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Development of Hydropower Engineering in the U.S.S.R.

(Razvitie gidroenergetiki SSSR)

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FOREWORD

"The present is the inheritance of the past. In order to judge the present we have to study the past; the two are interconnected, and by their interconnection they become clearer."

N. M. Karamzin. Istoriya Gosudarstva Rossiiskogo
(History of the Russian State)

One of the principal characteristics of the industrial power of a country is its level of power development. The large-scale development of the almost unlimited water-power resources of Russia as a basis for economic growth has always been the leading idea in all Soviet economic plans since the early days of the existence of the regime.

During the socialist regime, there has been a trend to utilize fully all the available water-power resources, not only for the development of power production, but also for navigation, agriculture, water supply, etc. The plans for the rapid industrial development of the country and the complete reconstruction of the whole national economy required the rapid construction of power plants and the use of locally available power sources. The power potential of Soviet rivers is tremendous; more than 108,000 rivers with a total length of more than 2.5 million kilometers flow over the vast territory of the Soviet Union. Their power suffices to drive 1800 large hydropower plants having a total power of more than 100 million kw, and about 20,000 small hydropower plants. According to figures from the Ministry of Power Plants, the potential water-power resources of the USSR amount to 3800 billion kwhr, of which 2100 billion are already technically exploitable.

In 1918, under the direct guidance of Lenin, the Soviet Union started to develop its hydropower resources.

On December 23, 1920, the VIII All-Russian Conference of the Soviets discussed and adopted the first comprehensive plan for electrification known as Lenin's GOELRO* plan.

Since that time, the Soviet Union has implemented more than 30 GOELRO plans. At present, Soviet power plants produce in one day the same amount of electricity as was produced during the whole of 1920. In terms of power generation, the Soviet Union occupies first place in Europe, and second place after the United States in the world. However, the pace of Soviet power construction markedly exceeds that of the U.S.A. During the last 30 years, power generation in the USSR increased by 13.4% and in the U.S.A. by 6.6%. In 1961, the installed capacity of the USSR reached 75 million kw, 22% of which was in hydropower plants. In 1952, it is intended to commission another 3 million kw of hydropower. This is,

* [For this and other abbreviations appearing in this text, see list on p. 280.]

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however, but a small part of the tremendous power resources of the USSR, 80% of which is concentrated in the eastern regions of the country.

The Seven-Year Plan, now being implemented, envisages a total capacity of hydropower plants of 30 million kw.

Three milestones mark the historical development of Soviet electrification: the construction of the Volkhov, Dnieper, and Volga hydropower plants [abbreviated throughout this text as HEP].

The construction of the Volkhov HEP represented the beginning of hydropower development in the USSR. This plant although, according to our modern conception of a power plant, a modest venture, was at the time impressive, and even today, by its engineering-efficiency figures, it can serve as an example for larger plants.

The Dnieper Power Plant im. Lenin [also known as the Dneproges] is the "firstling" of the Soviet Five-Year Plans. The huge dam crossing the Dnieper River raised Soviet power engineering to a world level, and for more than a quarter of a century, the Dneproges was the largest power plant, not only in the USSR, but also in all Europe.

Let us compare the scale of the first Soviet hydropower plants with some present-day projects: the first ten turbine units of the gigantic Bratsk HEP on the Angara River[1]* with a planned installed capacity of 4.5 million kw, were put into operation in September 1962; the power of a single unit of this plant exceeds by almost four times the power of the whole Volkhov HEP.

But even the Bratsk HEP is not the limit[2]. Now under construction is the Krasnoyarsk HEP, with a planned installed capacity of 5 million kw. Plans are being made for the construction of a still more powerful plant on the Yenisei River with a capacity of 6 million kw.

During the period from the construction of the first Soviet power plant — the Volkhov HEP — to the construction of the Bratsk and Krasnoyarsk HEPs, Soviet engineers have acquired wide experience in the design and construction of hydropower plants, under the most diverse conditions: on lowland and mountain rivers, on rock and soft foundations, even on sand and gypsum soil, in Karst regions, and in permafrost areas. Such a diversity of natural conditions determined the great diversity in design, construction, and working methods.

During this time, Soviet industry erected hundreds of large and medium-scale power plants, with a total capacity of about 17 million kw, and furnishing billions of kilowatt-hours. In only three days, Soviet plants produced as much electricity as was produced by all the Soviet plants during the whole of 1920!

A characteristic feature of Soviet power engineering is the construction of plants on large lowland rivers having large flood plains, small slope, and heavy ice conditions that require the construction of particularly massive structures on soft foundations (clay and sand).

The work of Soviet hydrologists, hydraulic engineers, hydrogeologists, and power-machinery constructors was invaluable in the solution of problems connected with the harnessing of rivers[3].

The impact of Soviet power engineering on other branches of the national economy was considerable. A vast network of waterways has been set up linking the White, Baltic, and Caspian seas with the Sea of Azov and the Black Sea, forming a unified waterway system in the European part of the USSR.

* [For notes, see p. VII.]

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Soviet achievements in power engineering are remarkable, a fact recognized even by Western leaders.

Thus, the [former] premier of Great Britain, Macmillan, has said: "The future offers great prospects to the Soviet people. What you see now is not a fata morgana but reality. The pace and quality of your [i.e. Soviet] progress is amazing and, as far as I know, is unparalleled in history"[4].

C. Marcelle, the chairman of the International Committee for Large Dams, while visiting the Soviet Union in 1962, stated: "During the thirties I worked for a long time as a consulting engineer to Soviet design institutes on hydropower plants. Since that time, the Soviet Union has gained remarkable achievements. I have visited many countries but I must frankly say that Soviet hydropower engineering can serve as an example for many countries. I was particularly impressed by the planning, powerhouse, turbines, and generators of the huge plant on the Volga near Volgograd. This plant is much larger than the most powerful hydropower plant in the U.S.A. — the Grand Coulee Plan"[5].

The diversity and scale of the problems dealt with in this study make inevitable some gaps in their treatment; but if the book quickens the interest of the reader in these problems and makes him aware of the great importance of harnessing the enormous water resources of the USSR, the author will consider his aim fulfilled.

The author hopes that this book has made clear to the reader the importance of harnessing water-power resources[6].

NOTES

[1]It is interesting to note that Averell Harriman, after his visit to the Soviet Union, published an article in the New York Times (25 June, 1959) in which he considered the construction of the Bratsk HEP a remarkable achievement of Soviet Engineering (reproduced in the "Literaturnaya Gazeta" of 2 July, 1959).

[2]Khrushchev: Pretvorenie v zhizn' leninskikh idei elektrifikatsii strany — vernyi put' k pobede kommunizma (Implementation of Lenin's Plan of Electrification—is the Correct Way to Achieve the Victory of Communism). — Gospolitizdat, 1959.

[3]Vneocherednoi XXI s'ezd KPSS 27 yanvarya — 5 fevralya 1959. Stenograficheskii otchet (The Extraordinary XXI Congress of the CPSU, 27 January — 5 February, 1959. Stenographed minutes), Vol.I, pp.63-64, Gospolitizdat. 1959.

[4]Reproduced in Pravda 24 February, 1959.

[5]Quoted from "Gidrotekhnicheskoe stroitel'stvo, 1962. No.8. p.6.

[6]Plan elektrifikatsii RSFSR (Electrification Plan of the RSFSR), p.75. Moskva. 1920.

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Introduction

THE HARNESSING OF WATER POWER IN RUSSIA BEFORE THE OCTOBER REVOLUTION

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ADVANCED IDEAS OF RUSSIAN SCIENCE

"The Russian scientist bore the noble banner of scientific thought
despite innumerable obstacles and difficulties, under the Tsarist regime."

S.I. Vavilov

Tsarist Russia was economically and technically backward, and the level of water-power development and hydroengineering was rather low.

Since the earliest times, waterways have played an important part in the economic life of the country, this importance increasing in the XVIII and XIX centuries. The well-known Russian hydraulic engineer Lokhtin wrote in 1904: "There is no country in the whole world where rivers and river navigation play such an important role as in Russia. The Russian people, Russian trade, Russian industry, Russian towns and villages[1] have all developed along waterways".

The following canal systems were constructed during the XVIII and XIX centuries: Vyshni Volochek, linking the Volga with the Baltic Sea, Mariinsk Canal; Tikhvin, Northern Dvina, Moskva River, etc. These canal systems comprised numerous navigation canals, locks, low-height dams, riparian, and other structures, built on a rather modest scale (which could not be otherwise at that time). Most of them were of simple design, and were built to last centuries.

Among the types of dam built, the most popular were the classical timber dams for heads of 3 to 4 m, navigable wicket (Chanoine or Begout) dams for heads of 3 to 5 m (built on the Sheksna, Moskva, Oka, and Northern Donets rivers), and several types of slightly higher concrete dams with plain sliding gates, used mainly in irrigation systems of Soviet Central Asia. Mention should also be made of the 21 m high masonry (mortar-bonded) dam on the Satka River, erected in 1910 for the Poroga Hydro-electric Plant in the Ural Area, as well as some old dams made of locally available materials, which are still in a good state of repair even today[2].

The water-outlet structures of the earthfill dams were mostly diversion channels (or spillways) with multistage timber overfalls or chutes, and were only seldom made of masonry or concrete.

Some of the navigable rivers (Dnieper, Upper Don, Volga) were provided with river-training (regulating) structures, mostly of composite construction using stone and brushwood-fascines.

The Upper Volga storage reservoir, known as the "Beishlot" Lake (the largest of its time [in Russia]) of 400 million m^3 holding capacity and 150 million km^2 water surface, was built in 1840 on the upper reaches of the Volga River. This reservoir was used and (after reconstruction) continues

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to be used to maintain a navigable depth on the Volga up to the town of Kalinin.

Water pipelines in these times were of small diameter (0.5 m) and length, and were built mostly in urban areas for water supply. Earth channels were used for irrigation in Soviet Central Asia and Caucasus, and for drainage in the western and northwestern regions.

Navigation channels were built within the framework of canal systems and constituted an important achievement of Russian engineering. Except for the Mariinsk canal system, which was maintained in quite a satisfactory state, these navigation channels were allowed to deteriorate. These systems, as well as the navigable Sheksna, Moskva, Oka, and Northern Donets rivers with long wide ship locks were the principal hydroengineering "inheritance" from Tsarist Russia. River management and water management were on an extremely low level in Tsarist Russia. There were, however, hundreds of thousands of rather primitive water mills with a total power of about 700,000 hp, as well as hydromechanical installations at various plants and factories built as far back as the XVIII century. These were situated in the Ural Area, Altai, Karelia, and Central Russia. These structures which, for their time, were of a high engineering standard, in the course of time became obsolete.

Although science was not promoted by the Tsarist government, progressive Russian ideas were developed and strengthened by the work of Russian scientists who wrote remarkable studies on hydraulics and hydraulic engineering. Important contributions to the development of Russian science can be found in such periodicals as the "Transactions of the Russian River-Navigation Society", "Collection of Studies by the Transportation Engineers", "Transactions of the All-Russian Society of Electrical Engineers", etc.

The single, more or less independent scientific institution at that time was the hydrotechnical laboratory of the Office for Transportation and Communication Facilities founded in 1907 in Petersburg by Professor V.E. Timonov.

At the mechanical workshops of the Moscow Higher-Engineering Institute, Engineer A.P. Permyakov organized the production of [hydraulic] turbines. During a period of 25 years (1884 through 1908) 40 turbines of various types were built and installed throughout the country.

In 1903, Professor I.I. Kukolevskii erected at the same institute a hydraulic laboratory which, until the October revolution, was mainly used for courses in engineering. Prerevolution hydrotechnical science had the benefit of a series of textbooks and monographs containing the theoretical and practical work of the following specialists: M.N. Gersevanov, F.G. Zbrozhek, B.N. Kandiba, and N.P. Puzyrevskii (waterways); V.M. Lokhtin, N.S. Lelyavskii, I.V. Bushmakin, E.A. Vodarskii, and V.E. Timonov (hydrology and river management); I.A. Evnevich, P.I. Mel'nikov, F.E. Maksimenko, I.A. Time, N.E. Zhukovskii, I.G. Es'man, and A.Ya. Milovich (hydraulics); I.A. Time, I.G. Es'man, and V.N. Pimegin (hydraulic engines), and, finally, D.D. Neelov and N.P. Puzyrevskii (dams).

Of particular (scientific) value were the publications of various offices and government agencies, e.g.,

1. "Materialy dlya opisaniya russkikh rek i istorii uluchsheniya ikh sudokhodnykh uslovii" (Data on Russian Rivers, and History of the

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Improvement of Their Navigation Conditions). This study consisted of 73 volumes and appeared during the years 1902 through 1917.

2. "Svedeniya ob urovne vody na vnetrennikh vodnykh putyakh" (Data on the Water Level in Inland Waterways), covering the period 1881 through 1910.

3. The "Ezhegodniki" (Yearbooks) edited by the OZY (Department for Land Amelioration and Reclamation) of the Ministry of Agriculture.

4. "Trudy soveshchaniya po opytnomu stroitel'nomu delu" (Transactions of the Conference on Experimental Building Techniques).

5. Various reports by the Department of Hydrometry of the Agricultural Agency in Turkestan, as well as reports by the Water Administration of the Caucasus, which have appeared since 1900.

6. The "Zhurnal Ministerstva Putei Soobshcheniya" (Journal of the Ministry of Communications and Transportation) and such periodicals as "Vodnye Puti i Shosseinye Dorogi", "Russkoe Sudokhodstvo" and "Vodnoe Delo".

Despite the remarkable achievements in Russian hydraulics in later centuries, it would not be just to pass silently over the achievements of earlier periods. Documents in archives referring to the XVI-XVIII centuries tell of the remarkable work of early scientists who, following their own ideas, were way ahead of the general level of science in the world[3].

An important factor in the study of river runoff and water storage is the study of the river net. Chronicles and historical documents show that the study of rivers and lakes as waterways had started in ancient times. Thus, toward the middle of the XVI century, the river net had been correctly reproduced in great detail on the map "Bol'shoi chertezh" (The Big Drawing), as well as in the book "Kniga Bol'shomu chertezhu" (The Book of the Big Drawing), published in Moscow at the beginning of the XVII century, and containing extremely important hydrographic data on Russia.[4]

Chronicles of the XVI century tell of the attempts of a certain inhabitant of the town of Pskov to harness the power of the Volkhov River. He tried to impound this river near the Novgorod Kremlin, and build a flour mill near the crib-work dam. Information exists suggesting that, at this time, the construction, not only of crib-work dams but also of masonry dams, was begun. During the XVII century, several plants were built and equipped with hydraulically driven machines. We must also mention a novel and comprehensive project of the XXII century for utilizing water power — a twelve-stage chain of water mills for the town of Kashira. This project is proof of the early familiarity of Russian technicians with the principles of harnessing rivers on an economic scale.

At the beginning of the XVIII century, M.I. Serdyuk, a self-taught hydraulic engineer, created the first large storage reservoir for river navigation, the so-called "Zavodskoe vodokhranilischche"(Plant Storage Reservoir) intended for the regulation of the Tsna and Shlina rivers, and for the supply of water for the Volga and Msta branches of the Vyshni Volochek canal system, which linked the Volga basin with the Baltic Sea. The water of this storage lake, which had a surface of 70 km^2 and a capacity of 170 million m^3, fed numerous water-power installations of industrial establishments — hence its name[5]. This reservoir, after reconstruction, is still in operation.

During the time of Peter the Great, river training and control reached a high level of development at the Ural plants. These plants diverted the

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overflow of several rivers into a single basin, thus ensuring a heavy flow to a single water wheel. These projects involved the building of water-conveying tunnels that reached a length of up to several kilometers.

Natural lakes were widely used for river-runoff regulation. Of particular interest is the project for the Pyskorka Plant erected in 1723, on one of the tributaries of the Kama River. The project provided for the construction of a chain of four dams, the upper one creating a storage reservoir which served as a seasonal runoff regulator for the whole chain (cascade). Chain-type river control was also used at the Olonetskii Plant; three storage lakes collected up to 75 million m^3 of water to feed eight water wheels of 165 hp each. The largest storage reservoirs of that time, the Vorkinsk, Upper Iset, and the Kyshtym lakes (in the Ural area), had a useful storage volume of about 100 million m^3, and a water surface of up to 70 km^2. The storage lake of the Verkhne-Neivyanskii Plant had a still larger capacity — 125 million m^3.

Of particular interest are the water and ice outlets in earth dams constructed during the reign of Peter the Great. These dams were equipped with water-deflecting ski-jump chute spillways — this idea being used by the Läufer-Pfletschinger Company[6] much later (1920).

Here it is necessary to mention the father of Russian science — M.V. Lomonosov, who displayed his remarkable talent in the field of hydraulic engineering also[7]. By his studies, he furthered the development of water-power installations in Russia; he designed and was responsible for the execution of the Ust-Ruditskaya Water-Power Plant. Lomonosov, who had considerable practical ability, carried out theoretical and experimental research on water-power plants and into methods for their improvement[8].

We should also mention a contemporary of Lomonosov — A.P. Hanibal (Ganibal) (1696-1781) (one of Pushkin's forefathers), who has now been completely forgotten. He was a remarkable water engineer, and specialist in the construction of canals. Hanibal made a remarkable contribution to the development of water management, and advanced the theory of hydrotechnology[9].

The Soviet Union claims to have constructed the first diversion-type water-power installations[10]. In 1754, I.I. Polzunov, the inventor of the steam engine, constructed a diversion water-power installation on the Korbalikha River in the Altai Region. Ten years later, the outstanding Russian hydrotechnologist, K.D. Frolov, constructed another diversion unit of improved design and higher power on the same river. The prime mover of this unit, a water wheel, actuated a whole series of working mechanisms. This was a step further in the development of water-power engineering.

In 1787 K.D. Frolov constructed at Zmeinogorsk (Altai Region) a four-stage submerged water-power unit, remarkable both in design and size. The unit was equipped with water wheels of giant sizes (diameters from 4 to 17 m). The water supply to the wheels was via tunnels. The four-stage cascade had a diversion channel of 2200 m length, and a submerged cavity in the rocks with a depth of more than 20 m.

The 18 m high earth dam built by Frolov 180 years ago is still in operation (Figure 1). The length of the dam along the crest is 158 m. The crest has a width of 12 to 20 m and the dam base is 82 m. The dam has a volume of about 100,000 m^3, and creates a storage lake with a water surface of 6.5 km^2 and a width of 2.5 km. The Zmeinogorsk Dam is of more daring

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design than many model earth dams[11]. It is interesting to note the use of slag as inverted filters at the rock toe of the dam.

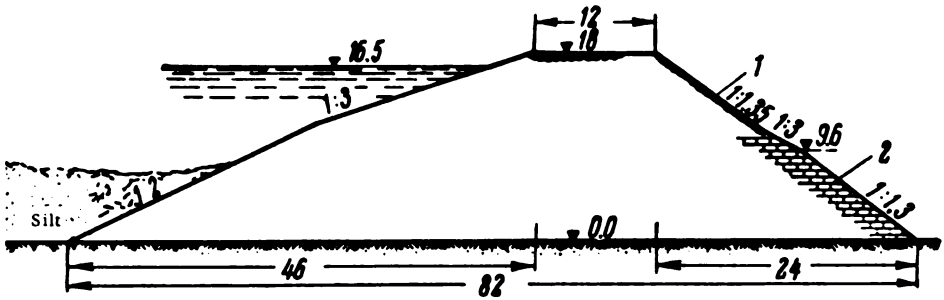

FIGURE 1. The Zmeinogorsk Dam constructed in the Altai Region in 1787 by K.D. Frolov (according to Academician V.V. Danilevskii)

1 — turf layer; 2 — dry-fill rock layer with bonded joints, up to an elevation of 11.0 m.

During the XVIII century, a number of important books appeared: a remarkable encyclopedia on the art and craft of building and on water-power engineering appeared under the title "Abrissy" (Sketches) by V. Genin (1737), the classical study by Lomonosov "Pervye osnovaniya metalurgii ili rudnykh del" (The Fundamentals of Metallurgy and Mining) (1763), the book by G. Makhotin "Kniga memorial'naya po zavodskom proizvodstve" (Handbook on Manufacturing) (1776), the vast work by V.A Levshin "Vseobshchee i polnoe domovodstvo" (Complete Art of House Building) (1795) dealing i.a. with the construction of dams and ponds[12].

These works show that, in the XVII and XVIII centuries, Russian engineers already knew the principles of rational water-management design, comprehensive utilization of water resources, correct selection of construction sites and layout of structures, construction of storage lakes for runoff regulation, effective means for increasing head and taking advantage of local conditions, etc.

It is amazing to see how Russian engineers of former times managed to erect such remarkable structures, with only primitive means at their disposal. In the past, water wheels were the main prime movers for various industrial needs. Low-power undershot water wheels, so popular in Western Europe, had already been replaced by the beginning of the XVIII century by overshot water wheels. The advantages of these wheels were known to Russian constructors before theoretical studies appeared abroad. Composite water wheels were widely used: at the Nizhni Tagil Plant, 57 water wheels with a total power of 610 hp were built in the eighties of the XVIII century.

The water wheel installed at the Kreenholm Mills on the Narova River was, in its day, the last word in engineering perfection. The various machines of the factory were driven by four water wheels each of 50 hp with the following characteristics: diameter 9.15 m; width 7.6 m; water discharge 9 m^3/sec; speed of rotation 4 to 4.2 rpm; head 5.2 m. The semi-overshot water wheel installed at the Kreenholm Mills, although only half the size of contemporary foreign water wheels, had twice their power, a fact clearly indicating the higher engineering talents of Russian technologists.[13]

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A shortcoming of water wheels as a source of power is their location on river banks or directly on rivers. This fact hampered the development of power engineering[14].

It is natural that attempts were made to improve the water wheel, so as to obtain higher powers from smaller wheels.

Many progressive ideas were developed in the St. Petersburg Academy of Sciences during the XVIII century. Thus, in the middle of this century, Lomonosov solved some of the general problems of the physics and mechanics of fluids. In the same academy, Daniel Bernoulli, using Galilean and Newtonian mechanics, and the concept of fluid pressure, analyzed the motion of a fluid in terms of energy, while Leonard Euler created "classical hydromechanics.". During the same period, he derived the turbine equation which ultimately had such an impact on the development of turbomachine design. He was also the first to develop the design of a hydraulic-jet engine, with a rotor and stator, i.e., both the basic elements of a modern hydraulic turbine. We see that the basis for the creation of a new form of water-powered machine was thus created.

In the thirties of the last century, the first practical turbines appeared. These paved the way for the further development of productive forces[15].

In 1837, the Russian dam constructor, I.E. Safonov, contemporary of the French turbine inventor Benois Fourneiron, constructed the first water turbine in Russia, not knowing of Fourneiron's invention. This turbine, with a power of 36 hp, was used to drive a roll mill[16].

Steadily improving his turbine, Safonov constructed several turbines with an efficiency of 70 %, which was quite high for his time[17]. These were installed in a series of Ural plants.

A.N. Uzatis, the founder of the Russian School of Mining Mechanics, suggested, in 1839, a simple but universal formula for the calculation of various types of [water] turbines. The need for such a formula was clearly appreciated. This was even more true after Uzatis showed that Fourneiron's formulae for the calculation of hydraulic turbines did "not give correct results, and that the turbines constructed according to these formulae in Germany were always a failure. Even the argument by which these formulae were derived was not really accurate and exact"[18].

A former student of the Kazan University, A.I. Neratov, contributed to the development of the theoretical understanding of turbines. In 1841 he published the world's first "curve for the operation of an engine". By "curve", he meant "turbine characteristic"[19]. It should be mentioned that such characteristics appeared abroad only after the publication of Francis' studies and invention in 1847.

In the middle of the XIX century, turbines were constructed in many plants in the Ural area, to designs developed by V.I. Rozhkov, I.A. Time, and also by I.A. Shilonosov, Kolpach, A.I. Permyakov, et al., working along the same lines.

In 1855, Rozhkov designed and installed in the town of Yekaterinburg, the first double-shaft horizontal axial turbine, equipped with two draft tubes; this type of turbine subsequently found wide application in many Ural plants. It is interesting to note that the first reference to this type of turbine is found not in Russian literature, but in the work of a German scientist, Julius Weissbach. In his "Mechanics", he spoke of Rozhkov's turbine as one of the best of this type"[20].

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Another Russian scientist, Professor I.A. Time, introduced many improvements into foreign turbine designs. A large model of a turbine designed by him received first prize at the Universal Exhibition in Vienna, in 1873.

In 1877, I.A. Shilonosov, a pupil of Time, designed and constructed a 75 hp turbine of the Girard type, for powering a sheet rolling mill. The water wheel had a diameter of 3.4 m and was of all-cast construction. For the time, it represented a remarkable technical achievement. Turbines to Shilonov's design replaced those constructed by the French engineer, Fontaine, which were widely used in Russian industry at that time.

The number of plants specializing in the construction of water turbines steadily increased; toward the end of the last century, there were already more than 12 such plants in operation. The largest among them were the Dobrov and Nabgol'ts plants in Moscow, Pirvits, Mantel, and Meier in Riga, Time in Opochka (Pskov District), etc. In 1865 the Dobrov and Nabgol'ts plants constructed a large number of turbines for various developments in Russia. In a report to the All-Russian Industrial Exhibition in 1882, it was stated that "this company has succeeded in designing and constructing turbines of progressive design, without which the mechanical energy of rivers cannot be used. The introduction of this field of engineering into Russia is an important contribution of this company"[21].

In 1877, one of the largest construction plants in Tsarist Russia — the Pirvits Works in Riga — started to build turbines. These were initially based on the Jonval and Girard systems, and on a combination of both systems. From the beginning of this century, turbines of the radial-axial and impulse (bucket)-type were made. Until 1917 this plant built more than 900 turbines of powers in the range 100 to 400 hp for both industry and agriculture.

Russian turbines were not inferior to foreign turbines and were frequently better. This fact was noticed both in Russian publications, and often in foreign literature as well, and was demonstrated at industrial fairs in which Russian turbine constructors actively participated.

When comparing the horse-power (braking) diagram of the vertical axial-radial turbine, constructed by the Pirvits Plant in Riga, with American hydraulic turbines, we see easily the advantages of Russian turbines over foreign designs with partial admission[22].

In the period 1882 to 1913, Russia imported 910 turbines with a total capacity of 60,000 hp. This represented about 40 % of the total hydropower capacity installed at that time in Russia. The maximum unit power of hydraulic turbines of Russian manufacture (of the Jonval, Girard, and axial-radial types) was 400 hp, and of imported units, 1200 hp (or 895 kw). The turbine (Girard system) installed at the Kreenholm Mills in Narva was, until 1895, the most powerful of its type in the world[23].

Table 1 represents data on the number and power of imported turbines and machines built at the largest Russian plants, during the period 1872 to 1916[24].

In 1908, much earlier than the idea appeared abroad, the Russian engineer, F.P. Morgunenkov, put forward the idea of using a propeller turbine for hydroelectric power generation. Later, V. Aleksandrov and A. Esaev were granted a state patent (No. 16942, dated 31 March, 1910) for a so-called "free-flow" hydroelectric power station with propeller turbines[25].

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TABLE 1

Hydraulic turbines in prerevolution Russia

Year of manufacture	Russian-made turbines			Imported turbines	
	number	total power, hp	average power of one unit, hp	number	total power, hp
1872 — 1880	80	2,128	26.6	6	1,369
1881 — 1890	233	7.907	33.9	40	3,624
1891 — 1900	460	12,277	26.7	198	12,727
1901 — 1910	1,237	42,277	34.3	356	27,431
1911 — 1916	1,040	36,425	35.0	43	5,125
Total for 44 years	3,050	101,014	33.1	643	50,276

THE FIRST RUSSIAN HYDROPOWER PLANTS

Despite success in the use of hydraulic turbines, hydraulic engineering was badly lagging behind other fields up to the eighties of the last century. This was due to the lack of a solution to the problem of transmitting the power derived from turbines over large distances.

For a long time the only way of using water power was its direct transformation into mechanical energy (using a rope or belt transmission). Such a transmission system was often installed over a distance of tens and even hundreds of meters. In some exceptional cases, such a transmission system (mostly using ropes) reached a length of several kilometers. This was done by erecting special towers at intervals of some tens of meters, provided with special rotating drums, and interconnected by endless ropes.

A remarkable example of such a rope transmission is the one put up at Okhta between the years 1865 and 1868, at a gunpowder plant near St. Petersburg, to a design by Professor N.V. Vyshnegradskii (head of the first Russian school of machine building), who also supervised the erection. The transmission linked the hydraulic turbines to the shops of the plant. These extended over several kilometers and were spaced 50 m from each other. "The Magnificent Okhta Installation", wrote Professor V.L. Kirpichev, "attracted considerable attention so that no wonder it was mentioned among the remarkable constructions of that time (see, e.g., the remarks of Jaquin in his "Les machines à vapeur"[26].

The Okhta installation proved the utility of rope transmissions: such installations were used in Switzerland for the transmission of power from the water-power plant at Schaffhausen on the Rhine and at Freiburg, etc. These transmissions covered distances of more than a kilometer. The installations were, however, expensive and their efficiency over long distances dropped to 20%. For this reason this type of installation did not gain wide acceptance. Another means for transmitting hydraulically derived power had to be found. The problem could only be solved by using electric transmission and distribution. This became possible only after the invention of the electric generator, transformer, and the system of high-voltage transmission.

Until recently, it was held that the first experiments on electric transmission were carried out by the French scientist, Marcel Depré at the

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Munich Exhibition in 1882. He established a connection between Munich and Missbach. Later, between Paris and Creil, he transmitted 40 kw at a voltage of 5000 over a distance of 56 km.

These experiments were not the first. Much earlier in St. Petersburg, the very first successful experiments in high-power transmission were carried out[27]. In 1874, a progressive engineer, F.A. Pirotskii, succeeded in transmitting 6 hp over a distance of about 1 km. He used the electricity to drive an electric street car[28]. In his paper "On the Transmission of Energy Derived from Water Power over any Distance, by Means of Galvanic Current", Pirotskii wrote, i.a.... "In view of the enormous expense involved in the maintenance of steam engines at large plants and factories, we considered the possibility of transmitting water power (the cheapest source of power) over a distance, using galvanic current obtained from an electric dynamo machine[29].

Pirotskii was also the author of a scheme involving a water-power installation, and electric transmission of current to the consumer. To quote from his study: "At a place with ample resources of water power, a water wheel or turbine should be installed. This is to be coupled to an electric generator (or dynamo machine) of a size corresponding to the power of the prime mover" (Figure 2). "From the generator, we must lay a metallic conductor (the other conductor being the earth) to a similar dynamo machine installed at the place the work is to be done; this machine should be linked through a shaft to the machines and lathes of the plant. The coupling of the water wheel to the dynamo-electric machine transforms the work of the wheel into galvanic current which, passing through a conductor, reaches a second similar machine. This transforms the current back into mechanical work. In this way, the machine will drive all the lathes and other machines connected to it"[30].

Pirotskii's ideas appeared to his contemporaries so unrealistic that the editor of "Inzhenernyi Zhurnal", in which his article was published, accompanied it with a note in which he declined any responsibility for the opinions of the author.

Pirotskii also devoted much attention to the study of areas with harnessable water resources, and wrote: "The water in the form of large and small waterfalls splashes down without being used". His primary reference was to the Narva waterfall.

Pirotskii's ideas and achievements were extended by his contemporaries—D.A. Lachinov and N.M. Alekseev. In 1880, prior to Depré by a considerable period, Professor Lachinov developed the fundamental theory of the transmission of electrical energy. He came to conclusions similar to those reached by Depré much later. This applies particularly to the efficacy of raising the voltage of long-distance transmission lines[31].

In his paper published on 25 August, 1882, N.M. Alekseev was the first to advance the idea of using the earth as a return conductor[32].

Direct current was the prevailing form of electrical energy at the end of the last century. It was also used for electric transmission, which imposed certain limitations on the power of the generator and the electric motor and thus on the distance of transmission. This was one of the reasons why, at that time, long-distance electric transmission developed so slowly.

A method of increasing transmission voltages, and the solution of many problems previously considered insoluble, became possible as a result

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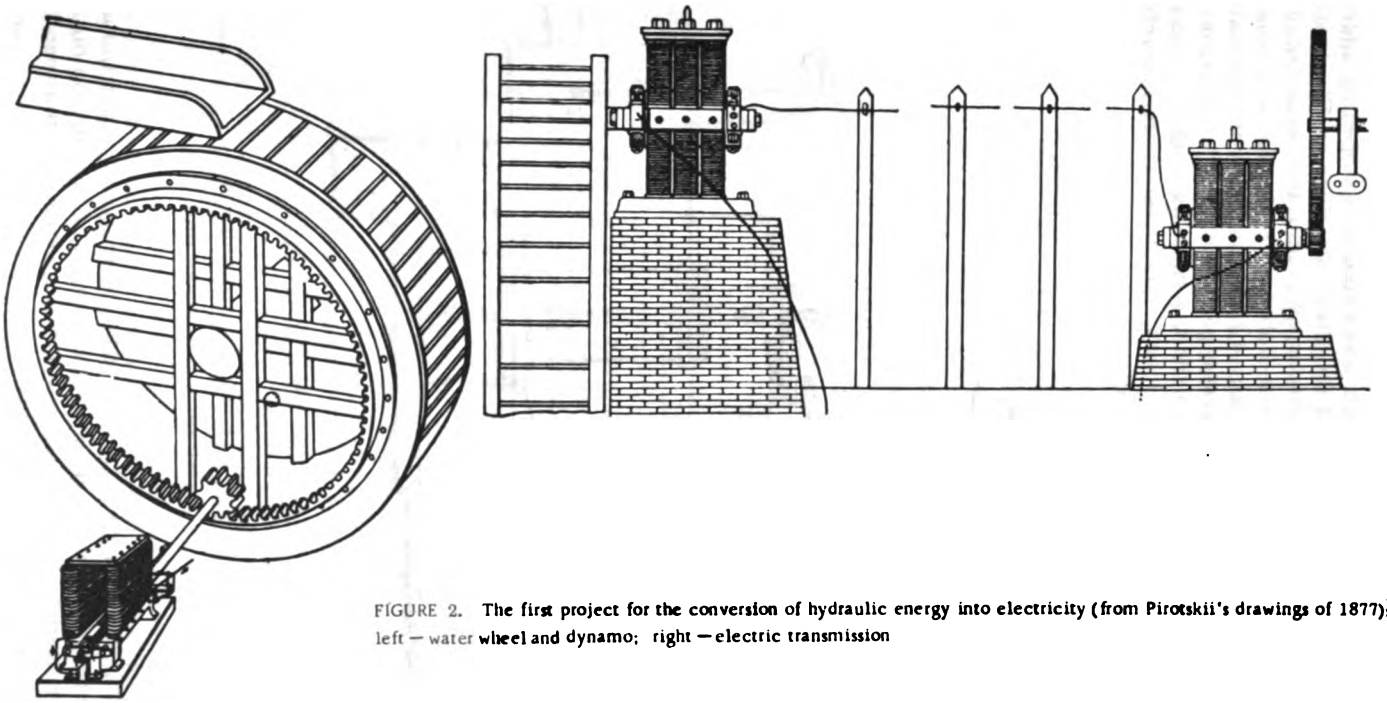

FIGURE 2. The first project for the conversion of hydraulic energy into electricity (from Pirotskii's drawings of 1877): left — water wheel and dynamo; right — electric transmission

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of the introduction of alternating current, invented by the Russian engineer, M.O. Dolivo-Dobrovol'skii. In 1899, the outstanding and world-wide importance of this invention was noted in his opening address by Professor N.P. Petrov, chairman of the First All-Russian Electrotechnical Conference. "It is pleasant for us to note the remarkable achievements of our Mikhail Osipovich Dolivo-Dobrovol'skii. Not only was he aware of the great importance of replacing direct current with alternating current, but he also appreciated the advantages of current transformation. More quickly and fully than Ferrari, he used the rotating magnetic field [invented by the latter] to surpass the Americans, and constructed powerful alternating-current motors."

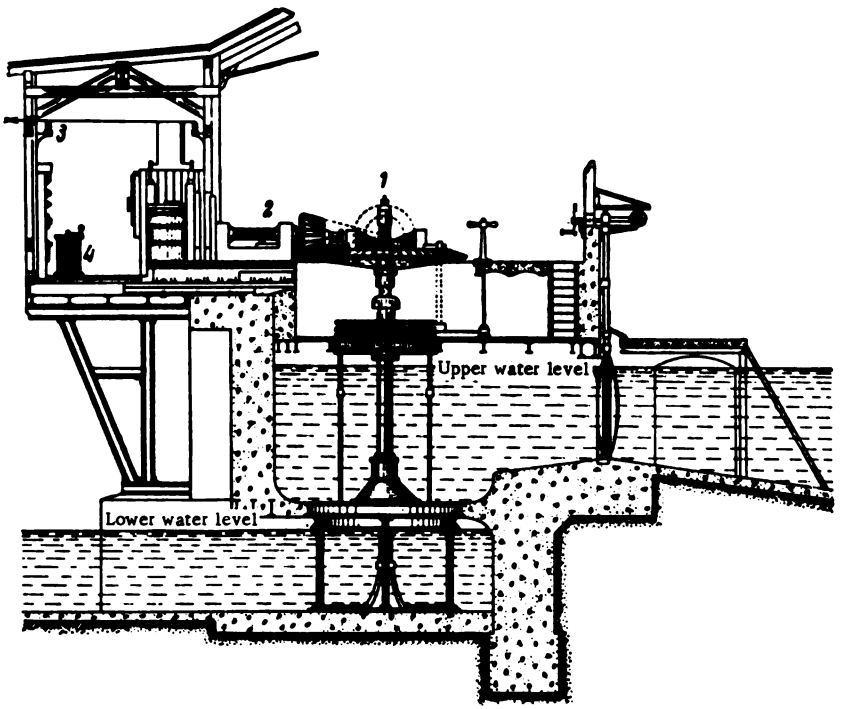

FIGURE 3. The world's first a-c hydroelectric station (in Laufen on the Neckar River, constructed by Dolivo-Dobrovol'skii in 1891:

1 — 300 hp turbine; 2 — a-c machine; 3 — transmission line; 4 — main transformer

The world's first large (300 hp) hydropower plant and associated 25 kv electric transmission line with a length of 175 km was built under the direct supervision of Dolivo-Dobrovol'skii in Germany, between Laufen and Frankfurt am Main in 1891 (Figure 3).

Dolivo-Dobrovol'skii's marvelous invention caused a revolution in electrical engineering and marked the beginning of a new stage in its

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development — the transition from hydromechanical to hydroelectric power plants.

In Russia, the first three-phase hydroelectric power station was built in 1896, at the Okhta Works in St. Petersburg, under the supervision of the well-known Russian electrical engineer, R.E. Klasson (who also participated in the construction of the Laufen Plant[33]. This power station was erected on the Okhta River and had a capacity of 270 kw.

The Okhta transmission line was constructed at a time when, abroad, it was even doubted that the problem of the parallel operation of three-phase generators would be solved[34]. The installation was the world's first example of a hydroelectric power station generating electricity for power and lighting, the power being transmitted over a considerable distance (3 km), as high-tension (2 kv) three-phase current.

The construction of the Okhta HEP served as convincing proof of the utility of three-phase current, and also marked the beginning of a new trend in electricity supply — centralization of generation. As far back as 1882, Lachinov wrote: "The versatility of electricity fathered in many scientists the idea of building a central plant from which electricity would be spread all over a town, providing it with light and power"[35].

The Okhta HEP became the prototype for modern power plants erected soon afterwards both in Russia and abroad.

While the Okhta HEP was being constructed, the first industrial high-voltage transmission line (with a length of 21 km) was being erected between a power plant on the Nygra River and the Pavlovskii mines of the Lena gold deposits in Siberia. Three-phase current at 140 v was generated at the Nygra HEP. The voltage was transformed to 10 kv [for transmission] and stepped down at the mines to 260 v. In the mines, three-phase electric motors of capacities from 6 to 25 hp were installed.

The Okhta HEP was of low head. On 15 January, 1899, shortly after its erection, a second high-head plant was commissioned at the health resort of Borzhomi. This served as further proof of the great potentialities of harnessing water power.

Like the Okhta HEP, the Borzhomi Plant produced three-phase current, which was transmitted at a tension of 2000 v. The transmission line from this plant had 5 step-down transformer stations. The installed capacity of the plant was 950 kw. The first stage of generation, with a power of 100 kw, was commissioned in 1899. In a technical report written in 1899, we read: "It is to be hoped that the Borzhomi Plant, which contains the first successful Pelton-wheel turbines to work with a high head (150 m), marks the start of the large-scale utilization of the power resources with which Borzhomi is so well endowed"[36].

In the same report it is stated that the Borzhomi Region: ". . . has huge power resources amounting to several hundred thousand hp". It was suggested that these resources be used for the illumination of Tbilisi and for the supply of current for electric traction on the Transcaucasian railroads. As a first stage, the plans provided for the electrification of the portion of the railroad passing over the high Suram Mountain, the terminal; to be at Khashurin, 30 km from Borzhomi. These plans are actually the first attempts to electrify the Caucasian railroads. However, this plan, like many other projects for the construction of HEPs in Russia, was not destined to be implemented: not a single kilometer of railroad was converted to electric traction during the Tsarist regime.

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The next long-distance transmission line was built by I.A. Time and M.A. Shatelen in 1902, in the Caucasus health-resort district.

A small HEP called "Belyi Ugol" [White Coal], with a power of 445 kw[37], was erected on the Podkumok River, near the town of Yessentuki. Electricity was transmitted at 8000 v to the towns of Pyatigorsk, Kislovodsk, and Zheleznovodsk supplying current for lighting, driving pumps, street cars in Pyatigorsk, and a freight railroad in Kislovodsk. Despite serious difficulties in setting-up and operation of the Mineral'nye Vody HEP, the project had extremely favorable results. However, the low volume of water flowing in the Podkumok River at some seasons of the year hampered the complete electrification of all the health resorts and spas. This is why the Yessentuki Plant was supplemented by another station in Pyatigorsk, equipped with diesel engines. The joint operation of these stations was carried out successfully. Mineral'nye Vody HEP was the first public utility in the world to supply electricity from a hydropower plant operated in parallel with a diesel-electric plant, located at a distance of 20 km from it.

The construction of the Mineralovodsk project was followed by another development erected in the Baku oilfields by R.E. Klasson. This comprised two large thermal power plants, separated by quite a large distance. The parallel operating plants provided a voltage of 20,000 v — the highest transmission voltage ever used in prerevolution Russia.

At the beginning of this century, most of the central power stations of the world provided three-phase current, and about 50 % of all electric motors operated on three-phase current. This was the beginning of the development of the "electrical industry — a development very typical of the recent successes in technology, of the capitalist system, at the end of the last, and the beginning of this century"[38].

The ability to transmit electricity over considerable distances made it possible to select the most favorable locations, with the greatest concentration of water power, as sites for the construction of efficient hydropower plants. All the early hydropower plants in the USSR are on waterfalls or river rapids.

In the last two decades before the revolution, Russian engineers designed projects for utilizing the power of the Volkhov, Dnieper, Narova, Vuoksa, Suna, and Svir, all large rivers. The designs were subsequently improved and the power of the projected plants markedly increased.

The idea of the electric "transmission" of the energy of waterfalls and river rapids, conceived by the engineer V.F. Dobrotvorskii in 1890[39], was realized in his project for utilizing the energy of the Narova and Volkhov rivers. Electricity was supplied to St. Petersburg. The project was unique in its novelty and large scale, and was much ahead of similar installations abroad. Moreover, Dobrotvorskii was the first in the world to develop a systematic project which would make it "possible to achieve simultaneously utilization of water power and improvement of navigation on these rivers"[40]. He also selected the optimum conditions for utilizing waterfalls. In other words, the idea of multipurpose river development was also born in Russia.

At the first All-Russian Electrotechnical Congress in 1899, Dobrotvorskii said, i.a: "My studies published during the last ten years clearly show that the utilization of the energy of rapids occurring on navigable rivers, may conveniently be combined with the construction of locks and the flooding of rapids, thus making possible the continuous passage of ships over the rapids. I was the first to have advanced this idea"[41].

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At the beginning of the nineties of the last century, Dobrotvorskii published his first project for a 20,000 hp HEP on the Narova Rapids. In 1895, he published his study "Snabzhenie goroda S. Peterburga elektricheskoi energiei, peredannoi ot vodopadov Narvskogo i Imatry" (The Generation of Electrical Energy from the Rapids of the Narova and Imatra Rivers and its Transmission to the City of St. Petersburg). This study contains the world's first exposition of the idea of hydroelectric systems. In 1899, he published another project for a dual-purpose development (navigation and power generation), on the Volkhov River. The project involved the construction of a 25,000 hp plant, provided with a unique rock-fill dam with gates and with water spilling over the dam crest [a spillway dam][42].

At this point we must mention that the Russian engineer and inventor, V. F. Dobrotvorskii, started to develop his ideas at a time when foreign projects, such as the development at Niagara, transmitted the power developed by ropes and compressed air. It was only in 1893 that a special U.S. Senate Committee came out in favor of electric transmission, and decided to: "adopt single-phase or two-phase current and certainly not three-phase current". It should be noted that this decision was adopted by the Americans at the time the remarkable invention of the Russian Dolivo-Dobrovol'skii was gaining wide acceptance in Europe.

The immediate impact of the deliberations of the first All-Russian Electrotechnical Congress on the development of hydraulic engineering can be gauged from this quotation: "The first installation for the transmission of the energy of waterfalls and rapids, designed by Dobrotvorskii, resulted in Russian engineers gaining valuable experience in the construction of similar projects, and served as an example for the construction of other developments for utilizing the natural power resources, in which Russia is so rich".

In his project for the construction of the Pskov-Yuryev [Tartu]-Narva waterway, published in 1905, the engineer E.L. Kenig suggested utilizing the Narva waterfall for river control, and for lowering the high level of Lake Chudskoe. As he wrote: "For the first time in Russia the problem arose of regulating the course of a river flowing out of a large lake"[44]. Kenig carried out calculations for this project, and designed a scheme for the control of the outflow from Lake Chudskoe into the Narova River.

In 1910, the engineer G.O. Graftio published his plan for the multipurpose harnessing of the Volkhov River and the construction of a hydroelectric station to provide three-phase current. The author of this project proposed to trasmit current to St. Petersburg, using a 110 kv line. The advantage of such a project was the provision for parallel operation of the Volkhov HEP and the thermal power plants of St. Petersburg. This project was rejected under the pretext that the experience then acquired in the use of such a high tension and in the combined operation of hydropower thermal plants was insufficient.

In his project, published in 1913, for the construction of locks and power plants at the Dnieper rapids, the engineer B.A. Bakhmetev was the first to introduce the concept of daily river regulation [daily pondage]. He also established the principles governing the use of Chanoine wicket gates to maintain the level in dam pools at a constant height. By carrying out detailed calculations on the proper use of the reserve capacity of steam-power plants, he was able to increase considerably the rate of water discharge through the dam [and thus the rated power output].

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As far back as 1913, one of the oldest members of the Russian Communist Party, the well-known power engineer G.M. Krzhizhanovskii, developed the idea of constructing a huge plant on the Volga near the town of Samara [Kuibyshev]. The location is almost identical with the site of the present-day Volga im. I.V. Lenin Hydropower Plant. A document preserved in archives (see Figure 4) shows the characteristic approach of the Tsarist officials to this project. Seven years later, Lenin entrusted the writing of the outline of the famous GOELRO plan to the same "blasphemer"*, Krzhizhanovskii.

All the projects for hydropower plants developed by such gifted Russian engineers as S.P. Maksimov, B.N. Kandiba, V.E. Timonov, V.P. Al'bitskii, G.F. Merching, A.I. Astrov, E.L. Kenig, M.A. Tokarskii, B.A. Bakhmetev, to mention but a few, were buried in the archives of the Tsarist ministries.

All these men invested great efforts in developing and disseminating the idea of utilizing "White Coal"[45].

The famous Russian man of science and patriot, D.I. Mendeleev, who, at the beginning of this century, raised the problem of drainage and irrigation of the Volga Area and other arid southern regions, wrote, i.a: "Land drainage is of the utmost importance in the development of the North. Here is another situation for a water-management scheme, in which the State can actively participate"[46]. The first scheme was the project "of irrigating large tracts of land in the arid areas of the lower Volga, Ural, Don, and Dnieper rivers"[47].

Of particular interest, and characteristic of the views of progressive people of this time, are the ideas expounded by E.O. Bukhgeim in his booklet "K ekonomicheskomu osvobozhdeniyu Rossii" (Thoughts on the Economic Liberation of Russia). In this, he speaks of "liberation by electrification". Sooner or later the electrification of Russia will become an urgent necessity for the improvement of the general well-being and productivity of the whole country. . ."[48]. He continues: "Theory and practice teach us that, given low-cost generation of power, electricity should become the universal energy source for the whole life of the country. . . It goes without saying that the liberation of Russia from economic backwardness and from dependence on foreign industry is inconceivable without electrification"[49].

No possibility existed for the realization of such plans during the Tsarist regime. Power generation and supply in Russia were then completely dependent on foreign capitalists, who considered the subject only from the point of view of using it to their own advantage[50].

As an example, Graftio's project (1914) for the construction of the Volkhov HEP, with 8 vertical Francis turbines totalling 80,000 hp, encountered fierce resistance on the part of the owners of St. Petersburg steam-power plants, who did not view with a friendly eye the appearance of a cheap source of electric power. The St. Petersburg city fathers were probably guided by similar considerations when they withheld approval of a project to construct a hydropower plant on the Vuoksa River for the supply of the urban street-car system. The appearance of cheap hydropower was also a thorn in the side of the British coal-mine owners, who furnished coal to St. Petersburg's thermal power plants.

* [See text of letter (Figure 4).]

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Other problems that could not be solved under the conditions of land-ownership existing under the Tsarist regime, were those of "the ownership of the energy of flowing waters" and the expropriation of the territory to be flooded by the storage reservoirs of projected power plants. "It is doubtful if the owners of vast lands along the Rion River would have agreed to the construction of large barrages on the river, resulting in the depreciation of their lands"[51]. This is the explanation of why, in its session of 18 March, 1910, the Commission for the Registration of Water Power in Russia declined approval for a project to harness the Rion River for the electrification of the mountain section of the Transcaucasian railroad.

Let us now follow the evolution of the schemes for utilizing the power potential of the Dnieper. For other rivers (including the Volga), not many designs were offered, and these only considered the navigation aspects of river development. With the advent of "White Coal", the question of using the potential of river rapids for power generation came to the fore. Twelve multipurpose schemes for utilizing the Dnieper rapids were drawn up[52].

The well-known specialist in hydraulic engineering (who subsequently became a member of all important councils for the construction of hydraulic projects in Russia), Professor B.N. Kandiba, published, in 1897-1899, his project for the construction of ship locks at river rapids. He proposed to use hydraulic engines both for the drive of lock mechanisms and ship lockage. These hydraulic engines were to be located at each of the nine canals provided with locks.

A further step in the improvement of the conditions of navigation, which also made use of the water power available [for other purposes], was the project for the construction of a continuous waterway between the Black and Baltic seas, thus linking the towns of Riga and Kherson. In 1905, a commission, headed by Professor M.N. Gersevanov, studied the proposed project and recommended that all navigation projects filed at the Management of Waterways should be revised with a view to utilizing the energy of the rapids for the benefit of the national economy[53].

Such an approach to the problem of combining navigation and the harnessing of the power of rivers furthered the idea of using the new principle of constructing locks combined with more or less high dams. The kinetic energy of the spilling water would be used for the production of power.

The first projects by S.M. Maksimov and G.O. Graftio (1905), A.M. Rundo and D.I. Yuskevich (1911), I.A. Rozov and L.V. Yurgevich (1912) were still mainly aimed at the improvement of river navigation, power generation being only a secondary consideration in "the use of abundant and freely available water power". These projects did not dwell on such important aspects as river training and river-runoff control; in fact, the use of nonoverflow dams, as envisaged by these projects, is incompatible with river training works. Disregarding electric-load fluctuations, the authors of all these projects provide for an exaggerated number of hours of annual operation of the power plant, and thus obtained exaggerated figures for the yearly power output and low figures for the cost of one kilowatt-hour[54].

The first project to depart from the conventional ideas was that of B.A. Bakhmetev (1913) [a hydraulic engineer also very well-known abroad]. The project deals with the comprehensive utilization of rivers for both navigation and power generation. Bakhmetev concentrated the head works

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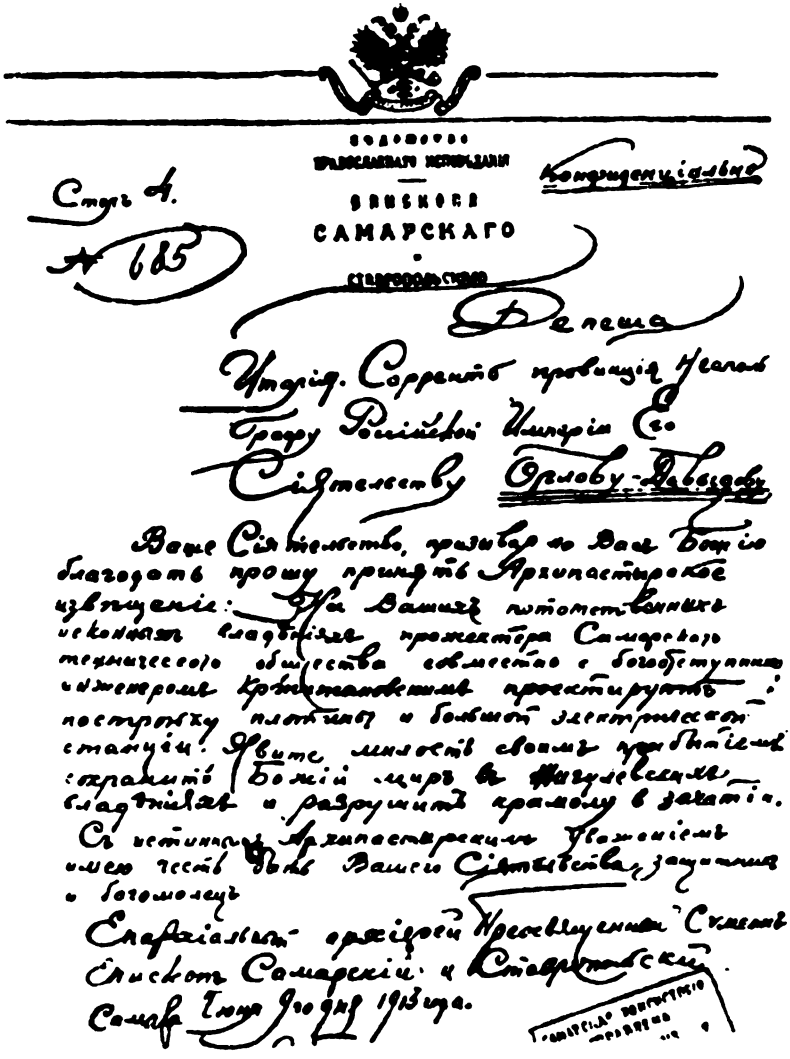

FIGURE 4. Photocopy of a document kept in archives on the construction of a hydropower station on the Volga near Zhiguli, in 1913. (Excerpts from secret correspondence between Bishop of Samara and Count Orlov-Davydov).

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so that the head could be harnessed using three turbine units (and not four, as in earlier projects). He introduced the concept of daily river pondage, and suggested the use of wicket-type dams for runoff control and for maintaining the water levels in both the upper and lower pools at the required height. He was also the first to suggest the idea of linking hydropower plants with steam-power plants, so as to provide reserve capacity for peak load demands.

An entirely new trend in the development of harnessing the Dnieper River was shown in the single-dam scheme devised by the engineer F.M. Morgunenkov (1913). He was the first to design a comprehensive power, transport, and irrigation development. The stress was on irrigation.

Morgunenkov's ideas had a strong influence on later work on water-management problems, particularly in the field of irrigation.

In 1914, the engineer I.A. Rozov suggested a two-dam scheme, but his suggestion met with strong opposition. This was due to the fact that the project would lead to the flooding of large areas; moreover, an erroneous conception was still prevalent among engineers that high-head dams could not be used in the cold climate of Russia.

In later projects for harnessing the Dnieper rapids, a tendency appeared to increase the pool length and the head to values that would ensure maximum use of the potential energy and the water discharge. The sole limitation was the need to provide a sufficiently high head to give easy navigation, without producing extensive flooding of the river plain. (Under the conditions existing at that time, this would have clashed with the interests of the land owners.) The rate of water discharge to give correct operation of a power station was taken at a minimum value, in the early projects. Later this rate of water discharge was slightly increased and the problem of increasing the effective head arose. All these ideas, however, were still in their infancy, and they did not give sufficient consideration to partial yearly runoff regulation, or to the combined operation of thermal power stations with hydropower stations, this scheme giving considerable advantages.

This old project of harnessing the Dnieper rapids was brought to life by the Soviet regime. Making use of some valuable ideas from these older projects, the skillful engineer, I.G. Aleksandrov (later to become a member of the Academy), together with a team of specialists, drew up in the twenties of this century, a new single-dam scheme for harnessing the Dnieper Rapids.

Nowadays, the conclusions drawn by the "Interdepartmental Commission for the Improvement and Development of the Waterways of Russia", which, in 1909, examined the project, sound anachronistic: "There is no immediate necessity to link the problem of constructing ship locks on the Dnieper with the utilization of the energy of the river. The rapids could easily be by-passed by navigation canals. The construction of such a canal should be the source of great benefits to the State, and would be more useful to navigation than the combined use of the rapids for navigation and power generation"[55].

Such were the conclusions of a Tsarist Commission at a time when large power stations were being built in Western Europe and North America, one after the other.

The following table gives the level of power construction in the years before World War I in some of the western countries[56].

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Name of plant	Country	Year of commissioning	Installed capacity, kw	Head, m
Rheinfelden	Germany	1898	12,500	3.2
Augst-Wyhlen, on the Rhine	Germany	1911	32,000	
Sir Adam Beck (Niagara)	U.S.A.	1900	370,000	41.2
Keokuk	U.S.A.	1912	133,000	

True, the total power of the Tsarist power stations [57] was [for that time] quite impressive — about 700,000 kw, and the number of water engines reached 50,000; however, most of this power was generated by water wheels and only 20 to 25% in turbines (of which there were 5000 with an average unit power of 30 kv and a maximum unit power of 900 kw). There were about 50 hydropower stations with a total power of 16,000 kw, i.e., they constituted about 2% of all water engines in Russia at that time.

TABLE 2

List of the most important power plants in Tsarist Russia (data for 1917)

Name of plant	Year of commissioning	Capacity, kw
Altai-Zyryanovsk Ore Mines, Berezaka River	1892	150
Okhta, Okhta River, St. Petersburg	1896	270
Tikhono-Zadonskii Gold Mines, Nygri River, Lenskii District	1896	300
Nadezhdenskii Gold Mines, Bodaibo River, Lenskii District	1898	290
Borzhomi, Georgia	1898	380
Aleksandrovskii Zavod, Petrozavodsk	1901	470
Afon (Novyi Afon Monastery)	1902	130
"Belyi Ugol" (White Coal), Yessentuki (town)	1903	445
Alapaevsk Works, Ural	1904	560
Gagry (Gagry — health resort)	1904	605
Nizhnii Gold Mines, Bodaibo River, Lenskii District	1905	535
Izhora Plant, Kolpino Railroad Station	1905	600
Izhevsk Plant, Izha River, Vyatka Province	1905	300
Two plants on the Razdan River supplying power to the town of Yerevan	1907 1911	280 220
Alaverdi, Armenia	1908	4820
Artvin, Batumi District	2nd half of XIX century	460
Besletka (Sukhumi)	1908	450
Satka (Poroga) Ural	1909	650
Vasil'evskii Gold Mines, Bodaibo River, Lenskii District	1910	750
Murgab (Hindu Kush) in Soviet Central Asia	1910	1000
Chakva (Fefelevskaya), Gruziya	1913	175
Artemovskii Gold Mines, Bodaibo River, Lenskii District	1914	250
Turgusun, Turgusun River, tributary of the Bukhtarma River, Altai	1916	1000
Chuiskaya, Turkestan	1917	445

The hydroelectric resources of Russia had been investigated to only a small extent and, according to data of the Ministry of Agriculture, amounted, in 1916, to 15 million kw[58]. Thus the 700,000 kw produced represented an extremely small percentage of the existing power resources.

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By 1917, Tsarist Russia occupied one of the lowest places in the world as far as the utilization of waterpower was concerned. Compared with 1916 (see Table 2 below) there are now in the Soviet Union many rural power stations that exceed the most powerful plants of Tsarist Russia.

As seen from the table, the most powerful stations at that time were the following: 1) Alaverdi HEP in Armenia of 4820 kw[59] (three Kaplan turbines); 2) the Turgusun HEP in the Altai Territory, supplying current to a metallurgical works owned by foreign interests; 3) the Murgab HEP in Russian Central Asia at the Hindu Kush Dam, for the supply of electricity to one of the numerous Tsarist estates. The output of this plant was, for the year 1914, 2,500,000 kwhr. Electricity was transmitted as three-phase current over a distance of 40 km at a tension of 16.5 kv. An interesting feature of this plant was the use of a turbine pump produced by the Riga works "Pirvits". This gave a head of 8.5 m and a discharge rate of 1450 liter/sec, and was used for the irrigation of nearly 2000 ha of land.

Apart from the plants listed in Table 2, several minor plants with unit powers of up to 100-150 kw were built to supply electricity to some country houses, castles, and factories[60,61].

A clear picture of the backwardness of Tsarist Russia in the field of electric-power generation emerges from a comparison with foreign countries. The total installed capacity of Tsarist hydropower plants in 1916 (16,000 kw) was 1.3% of the total unit power capacity (1,190,000 kw). The total output of hydropower plants (37,000,000 kwhr) was only 1.4% of the total output in 1916 (2,575,000 kwhr). The total installed capacity of all the Tsarist power plants was only half the capacity of the Volga HEP imeni Lenin.

At that time, Germany produced 5 billion kwhr annually, and the U.S.A. 22.5 billion kwhr.

In Tsarist Russia, the per-capita consumption of electricity was only 14 kwhr per year — 1/20 of the consumption in the U.S.A.

With a total installed capacity in Tsarist Russia of 1200 Mw, the average number of hours each installed kilowatt was used in one year was 1770[62], a figure that illustrates the "snail's" pace of the development of production forces in Russia. The installed capacity was only 21% used.

We shall now look at the position of transmission lines in Tsarist Russia. In 1913, the total length of low-voltage lines (11 to 30 kv) was 109 km. In 1914, another 76 km of line operating at the highest voltage used at that time — 70 kv — were added. There were no power networks as they are known today. Even large towns had many small power plants, with a great variety of voltages, frequencies, and types of current.

The picture changed radically after the October Revolution. The Soviet regime undertook measures to achieve the rapid utilization and development of the abundant water-power resources of the country. In an extremely short time it was possible to raise the country to one of the first places in the world in the field of power generation.

NOTES

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[2]Nesteruk, F. Pervaya russkaya dissertatsiya po gidrotekhnike (The First Russian Thesis on Hydraulic Engineering).—Gidrotekhnicheskoe Stroitel'stvo, No. 12. 1946. See also Figure 54.

[3]Danilevskii, V. Istoriya gidrosilovykh ustanovok Rossii do XIX v. (History of Waterpower Installations in Russia up to the XIX Century), Moskva. 1940; Nesteruk, F. Gidrotekhnicheskoe proshloe velikogo goroda (Early Hydraulic Engineering Achievements of a Great City), Moskva, 1947; Idem. Vodnoe stroitel'stvo Moskvy (Water Management and Construction in Moscow), Moskva. 1950.

[4]Nesteruk, F. Kniga Bol'shomu chertezhy, ili drevnyaya rossiiskaya gidrografiya (The Book of the Big Drawing, or Ancient Russian Hydrography).—Gidrotekhnicheskoe Stroitel'stvo, No. 9. 1945.

[5]Nesteruk, F. M.I. Serdyuk—stroitel' Vyshnevolotskikh gidrosooruzhenii (M.I. Serdyuk—Constructor of the Vyshni Volochek Hydrotechnical Structures).—Gidrotekhnicheskoe Stroitel'stvo, Nos 5-6. 1946; and the book "Mikhail Ivanovich Serdyuk—stroitel' Vyshnevolotskoi vodnoi systemy (M.I. Serdyuk—Constructor of the Vyshni Volochek Water System), Edited by F. Ya. Nesteruk, Moskva. 1952.

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[7]Nesteruk, F. Genii russkoi nauki M.V. Lomonosov kak gidrotekhnik (The Genius of Russian Science, M.V. Lomonosov, as a Hydraulic Engineer).—Gidrotekhnicheskoe Stroitel'stvo, Nos. 4-5. 1945.

[8]Nesteruk, F. Nauchnye idei i trudy M.V. Lomonosova po vodnomu khozyaistvu i gidrotekhnike (The Scientific Concepts and Work of Lomonosov in the Field of Water Management and Hydraulic Engineering). —Rechnoi Transport, No. 11. 1961.

[9]Nesteruk, F. Predki A.S. Pushkina—vydayushchiesya inzhenery i deyateli vodnogo khozyaistva (Pushkin's Forefathers—Outstanding Engineers and Specialists in the Field of Water Management).—Rechnoi Transport, No. 2. 1962.

[10]In diversion installations most of the available head is created by diverting the water through diversion (by-pass) channels parallel to the river bed and having a slope much smaller than the latter. The dam, which usually crosses the river bed at the entrance to the diversion channel is of low height and serves mainly for the diversion of the river water into the channel. Diversion-type hydropower plants are most frequently built on mountain rivers of high slope.

[11]The steep slope of this dam (reaching values of 1:1.5 to 1:2) is unusual even in modern dams and is found, e.g., in the Cabazzeras Dam in Brazil (40 m height).

[12]Nesteruk, F. 150-letie pervogo russkogo pechatnogo rukovodstva po plotinam (The First Handbook on Dams Printed in Russia 150 Years Ago). —Gidrotekhnicheskoe Stroitel'stvo, Nos. 5-6, p. 30. 1946.

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[13]Nesteruk, F. Pervaya gidrosilovaya ustanovka s moshchnymi vodyanymi dvigatelyami (The First Water-power Installation with Powerful Water Engines).—Gidrotekhnicheskoe Stroitel'stvo, No. 10, p. 29. 1948.

[14]Marx, K. Kapital (Capital), Vol. 1.—Gospolitizdat, p. 383. 1949 [Russian Edition].

[15]Idem.

[16]I. E. Safonov called his turbine a "horizontal water wheel". The term turbine is of French origin meaning top (gyroscope). (See Nesteruk, F. K120-letiyu termina "turbina" (The 120th Anniversary of the Birth of the Word "Turbine").—Gidrotekhnicheskoe Stroitel'stvo, No. 12, p. 29. 1946.

[17]Rozhkov, V. Opisanie turbin ustroennykh v Alapaevskikh zavodakh (Description of Turbines Constructed at the Alapaevsk Works).—Gornyi Zhurnal, No. 7. 1842.

[18]Uzatis, A. Opisanie turbin Furneirona (Description of Fourneiron's Turbines).—Gornyi Zhurnal, No. 4. 1839.

[19]Neratov, A. Vychislenie deistviya i opisanie ustroistva gidravlicheskikh koles (Description and Calculations on Water Wheels), Kazan. 1841.

[20]Weissbach, J. Lehrbuch der Ingenieur- und Maschinen Mechanik, Part 2, IV Edition, pp. 686-687, Braunschweig. 1865.

[21]Report to the All-Russian Art and Industry Exhibition, Moscow, 1882. Edited by V. P. Bezobrazov, Vol. IV, p. 44, St. Peterburg. 1884.

[22]Catalog of the Pirvits Company, p. 16, Riga. 1912.

[23]Nesteruk, F. Pervaya gidrosilovaya ustanovka s moshchnymi vodyanymi dvigatelyami (The First Hydropower Installation with Powerful Water Engines).—Gidrotekhnicheskoe Stroitel'stvo, No. 10, p. 30. 1948; see also Trudy Instituta Istorii Estestvoznaniya i Tekhniki AN SSSR, Vol. 44, 1962 by the same author.

[24]Moskvitinov, I. Belyi ugol' v Rossii (White Coal in Russia), Petersburg. 1923.

[25]Vestnik irrigatsii, Nos. 4, 6, 7, and 8. 1924. It is worthwhile to mention that the existence of records of these inventions in the archives of the Soviet Committee for Inventions, and the records of the project for the design of an axial turbine for the Kochetovka HEP, was the reason why the Austrian Professor Viktor Kaplan was not granted patent rights for his invention in Russia [obviously the reference is to the famous Kaplan turbine].

[26]Kirpichev, V. N. V. Vyshnegradskii kak professor i uchenyi (Vyshnegradskii, Professor and Man of Science), St. Petersburg. 1895.

[27]Nesteruk, F. Prioritet russkikh izobretatelei v oblasti peredachi elektroenergii na rasstoyanie (Russian Priority in the Invention of Electric Transmission over Large Distances).—Gidrotekhnicheskoe Stroitel'stvo, No. 1. 1950.

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[28]The first foreign attempt of converting water power into electricity dates back to 1876 and was achieved in Bavaria at the Linderhof Castle, with the object of illuminating the Royal Park and Grotto. During 1880 and 1881, both in Bavaria (Laufer) and Great Britain (Greyside) several hydropower stations were constructed.

[29]Inzhenernyi Zhurnal, No. 4, p. 445. 1877.

[30]Inzhenernyi Zhurnal, No. 4, p. 446. 1877.

[31]Lachinov, D. Elektromekhanicheskaya rabota (Electromechanical Energy).—Elektrichestvo, Nos 1, 2, 5, 6, 7. 1880. It is interesting to note that the editor of "Elektrichestvo" in writing on Depré's work, rightly stated: "This law was formulated by Lachinov in 1880, in almost the same terms" (Elektrichestvo, p. 269. 1882).

[32]Alekseev, N. Peredacha raboty na rasstoyanie (Transmission of Energy over [Long] Distances).—Tekhnik, No. 5, p. 3. 1882.

[33]Klasson, R. Elektricheskaya peredacha sily trekhfaznymi tokami na Okhtenskikh parovykh zavodakh bliz Peterburga (Electric Transmission of Three-Phase Current, at the Okhta Steam Works near St. Petersburg). Elektrichestvo, No. 19. 1897.

[34]It should be mentioned that the first Niagara Station, built in 1895 with a power of 450 kw, supplied direct current. The station was converted to three-phase working, at a later date.

[35]Elektrichestvo, p. 269. 1882.

[36]Data were drawn from a manuscript written by F. F. Moldenhauer (the initiator and constructor of the Borzhomi Plant in the year 1890) — put at the disposal of the present author by Prof. N. M. Shchapov — and from Moldenhauer's "Elektrichestvo v Borzhome" (Electricity in Borzhomi), Tiflis. 1899.

[37]The "Belyi ugol'" HEP works up to the present time; its capacity is 665 kw.

[38]Lenin, V.I. Sochineniya (Works), Vol. 22, p. 233.

[39]Dobrotvorskii, V. Elektroperedacha sily porogov Volkhova, Narovy, Imatry v Peterburg (The Transmission to St. Petersburg of Electricity Generated by Harnessing the Volkhov, Narova, and Imatra Rivers). — Trudy Pervogo Vserossiiskogo Elektrotekhnicheskogo S'ezda, 1899, Vol. III, p. 348, St. Petersburg. 1900.

[40]Ibidem, p. 296.

[41]Ibidem, p. 348.

[42]Ibidem, pp. 300-302; see also: Nesteruk, F. Gidrotekhnicheskoe proshloe reki Volkhova (The Hydrotechnical History of the Volkhov River).—Gidrotekhnicheskoe Stroitel'stvo, No. 11. 1946.

[43]"Trudy Pervogo Vserossiiskogo Elektrotekhnicheskogo S' ezda", Vol. I, p. 236, St. Petersburg. 1900.

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[44]Kenig, E. and I. Zhivilov. O proekte nepreryvnogo Pskovo-Yur'evo-Narvskogo vodnogo puti (On the Pskov-Yuryev Narva Continuous Waterway), St. Petersburg, pp. 14-15. 1909; Nesteruk, F. Krengol'mskaya gidrosilovaya ustanovka (The Kreenholm Water-Power Installation).—Trudy Instituta Istorii Estestvoznaniya i Tekhniki, Vol. 44. 1962.

[45]The term "white coal" (houille blanche) was coined in 1867 by the French engineer Aristide Bergès, who spread the idea of utilizing the power of large waterfalls, and the energy stored in snows and glaciers. The head used for power generation, at that time was 200 m (1869), and reached 500 m (in 1882 at the power plant erected in the Lancey Valley in the Department of Isère).

[46]Mendeleev, D.I. Sochineniya (Works).—Izdatel'stvo AN SSSR, Vol. XVI, p. 343. 1951.

[47]Ibidem, p. 345.

[48]Bukhgeim, E.O. K ekonomicheskomu osvobozhdeniyu Rossii (On the Economic Liberation of Russia), p. 27, Moskva. 1915.

[49]Ibidem, pp. 31 and 32.

[50]Whereas the share of foreign capital in Russian heavy industry was from 30 to 35%, in electrical engineering it was 70% on average. In the latter industry, the share of foreign capital was distributed as follows: German 81%, Swedish 10%, British 5%, Austrian 2.5%, and Italian 1.5%. See "Kratkii obzor sostoyaniya elektrokhozyaistva v 1921, v Rossii (Short Review of the Electrical Industry in Russia, in 1921), p. 17, Moskva. 1923).

[51]Trudy komissii po elektrogidravlicheskoi opisi vodnykh sil Rossii (Proceedings of the Commission for the Registration of Water Power in Russia), Vol. I, p. 120, St. Petersburg. 1911.

[52]Nesteruk, F. Proekt shlyuzovaniya i ispol'zovaniya vodnykh sil Dneprovskikh porogov, 1923-1924 (A Scheme for Lock Construction, and Utilization of the Potential Power of the Dnieper Rapids, 1923-1924).—Arkhiv Leningradskogo Instituta Inzhenerov Putei Soobshcheniya.

[53]Tekhnicheskoe opisanie proektov Chernomorskogo-Baltiiskogo vodnogo puti (Technical Description of Projects for the Black Sea-Baltic Sea Canal).—Materialy dlya Opisaniya Russkikh Rek, No. IX, St. Petersburg. 1906.

[54]Nesteruk, F. Istoriya vodokhozyaistvennykh i gidrotekhnicheskikh meropriyatii v basseine Dnepra (The History of Water Management and Water-Power Construction in the Dnieper River Basin).—Trudy Instituta Istorii Estestvoznaniya i Tekhniki AN SSSR, Vol. II, pp. 274-313. 1957.

[55]Byulleten' Mezhduvedomstvennoi komissi dlya sostavleniya plana rabot ... St. Petersburg, No. 5, p. 198. 1909.

[56]Nesteruk, F. Gidroenergeticheskie resursy mira (Water-Power Resources of the World), p. 65, Moskva-Leningrad. 1946.

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[57]See "Plan elektrifikatsii RSFSR" (Plan of Electrification of the RSFSR), p. 65, Moskva. 1920.

[58]Romanskii, E., A. Morozov, and S. Przhibyl'skii. O belom ugle (White Coal), p. 17, St. Petersburg. 1916.

[59]Moskvitinov, I. Belyi ugol' v Rossii (White Coal in Russia), p. 22, St. Petersburg. 1923. (The study was actually published in 1919 for a later French edition for the series "The Natural Wealth of Russia".)

[60]The drawing up of a complete list of Tsarist hydropower plants is not an easy undertaking as, even for the most powerful plants, only a minimum of figures are available. See also a typical comment in the standard work published under the guidance of M. M. Kovalevskii "Facts and Figures on Science and Technology" (Vol. III, p. 169, Moskva. 1912): "It seems (!?) that the largest water-power plant in Russia was in Turkestan — on the Murgab estate of the Tsar."

[61]More accurate data on Siberian hydropower plants, particularly for the plants in the Lenskii ore deposits and gold mines were obtained from V. V. Alekseev, lecturer at the Irkutsk University.

[62]Increasing the utilization of installed capacity is an important means for increasing power production: output increases without the need for any additional investment. However, this increase is limited by the maximum number of hours in a year (8760), and we must always provide reserve capacity for emergencies, repairs, load fluctuations, etc. Increase in the number of hours of utilization is only rational up to a certain limit, about 5500 hours per year.

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Chapter I

LENIN'S GOELRO PLAN AND THE UTILIZATION OF WATER POWER

"The Academy of Sciences, which initiated a systematic study of Russia's natural productive forces, should immediately proceed, through its Supreme Council of National Economy, to organize a series of commissions of specialists. These commissions should quickly draft a plan for the reorganization of Russia's industry and economy.

Such a plan should provide for: . . . . the utilization of low-grade fuel (peat, low-grade coal), the generation of electricity as cheaply as possible, the extraction and transportation of fuel, and the development of hydraulic prime movers and wind-driven motors, with particular stress on their utilization in agriculture."

V. I. Lenin, Sochineniya (Works) Vol. 27, pp. 288-289

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Lenin, the organizer of Socialist Electrification gave much attention to utilizing water resources, and to water-power development. He watched with the greatest interest the tremendous development of electrical engineering in France, Germany, Great Britain, etc., and was fully aware of the technical revolution brought about by the use of electricity.

In an annotation to Karl Kautsky's "The Agrarian Problem", Lenin wrote that electricity would play a greater role than steam. This would result from the ease with which electrical energy can be transmitted, and the small size of electric motors[1].

In one of his studies Lenin writes, i. a. "Electricity is cheaper than steam power, is more flexible and can be transmitted over great distances. Machines powered by electricity operate more smoothly and accurately"[2]. In the same article, he stressed the significance of regarding waterpower as an economic factor: "Industry will also be dispersed over the whole country for it also needs water. Utilizing waterfalls, canals, and rivers for power generation will have an influence on this industrial dispersion as well"[3].

In analyzing the development of capitalism, the concentration of capitalistic industry, and the development of technology under capitalism, Lenin drew attention to the centralization of electricity supply to factories, in large power plants located at great distances from the consumer.

In his draft for a study entitled "Future Tasks for the Soviet Regime" published in March-April 1918, Lenin notes the term "white coal". He writes that the Soviet Republic possesses enormous mineral riches and water-power resources". The exploitation of these riches, using the means of modern technology will constitute the basis for unprecedented progress in developing the production forces of the country"[4].

In his plan, "Scientific and Engineering Projects", published in 1918, Lenin recommended the Academy of Sciences to set up a series of commissions, which would draw up plans for economic construction, and for carrying out a scientific investigation of the natural riches of the country. In this study, Lenin formulates the socialist principles of locating industry close to sources of raw materials, and the rational geographic distribution of industrial enterprises. He paid particular attention to the electrification of industry and agriculture to make use of locally available fuel and power sources[5].

In this historic document, Lenin outlined the path that should be taken by hydraulic engineering, and explained the technological basis for industrialization.

G. M. Krzhizhanovskii has said: "These lines were written by Lenin, long before his meeting with the members of the GOELRO Commission. His letter to the Academy was a directive for the future work of the Commission. We must always bear in mind these words, which form a milestone in our path toward electrification"[6].

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In 1918, Lenin signed the decree for the construction of the Volkhov and Svir HEPs, and the preparatory stages of the construction of the Volga-Don Canal and some other hydrotechnical structures.

In the years between 1918 and 1920 work started on the design of a hydropower plant, to be erected at the Samara Bend of the Volga[7]. In 1920, a new version of the project for erecting a hydropower plant of about 1000 Mw at Zhiguli was developed. "Transmission of electricity generated at this plant over distances of 400 to 500 verst will supply many towns (Kazan, Saratov, Penza, etc.), thus changing the life of the Volga Area entirely"[8].

Lenin was also the initiator of the world's first state hydrologic institute, set up in 1919.

1 June, 1921, Lenin gave his approval to the 1921 construction program for electric power plants. Particular stress was laid on the design and construction of the state power plant to be put up on the Dnieper[9]. Several months later, in a letter to communists of the Caucasus region he wrote "We must spare no efforts to develop the production forces of this region; this applies particularly to natural wealth: white coal, and irrigation"[10].

In 1922, under the direct guidance of Lenin, a start was made on Zemo-Avchalskaya HEP.

He also participated in the official opening of a small hydropower plant, on the Lama River[11] near the village of Kashino.

After the Civil War, a period of feverish construction started, and the problem arose of developing a long-term plan for the electrification of the USSR. Lenin stressed the importance of such a plan at a session of the VTsIK "We need a technical basis for our economic-construction program: we shall have to build practically everything. This will take many years"[12].

Under the guidance of Lenin, a State Commission for the electrification of the USSR was set up headed by G. M. Krzhizhanovskii, with the participation of I. G. Aleksandrov (a well-known Soviet hydraulic engineer), G. O. Graftio, A. V. Vinter, B. E. Vedeneev, etc.

The commission, also known as GOELRO, published a basic plan, "Plan for the Electrification of Russia"[13]. This was called by Lenin the Second Program of the Party[14]. It was adopted at the VIII All-Russia Session of the Soviets on 23 December, 1920.

The plan was finally approved at the IX All-Russia Session of the Soviets on 23 December, 1921. Addressing the Session, Lenin said: "During the years 1918 and 1919, we built 51 power plants, while during the years 1920 and 1921, the number of plants built and commissioned rose to 221, with a total capacity of 12,000 kw. Of course, compared to what is being done in the West, these are only insignificant figures. Nevertheless, they clearly show what can be done despite almost unsurmountable difficulties"[15].

The GOELRO Plan, in accordance with Lenin's directives, outlined the future development of electrification, utilizing local fuel, and the energy of innumerable water-rich rivers[16].

The GOELRO Commission "explained the importance of carrying out an investigation of the natural wealth of the country, preparing qualified personnel, and explaining to the people of the Soviet Union the need to utilize the country's water-power resources"[17]. This would be a first step toward the realization of the Plan.

According to the Plan, 21 thermal power plants, operating on cheap peat and local fuel, with a total installed capacity of 1,110,000 kw, together with

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some tens of large hydropower plants, with a total capacity of 640,000 kw would constitute the backbone of the electrification program for the next 10-15 years. Among these plants, mention should be made of some of the first Soviet hydropower projects — the 30,000 kw Volkhov HEP, the two Svir HEPs, together providing 100,000 kw, and the largest HEP of the time, Aleksandrovskaya (later renamed the Dnieper HEP) of 200,000 kw[18].

The plan also envisaged the construction of six other plants: two on the Kuban River (at the headwaters of the river near the town of Krasnodar) with capacities of 40,000 and 20,000 kw; one plant on the Chusovaya River in the Ural Area (25,000 kw); one on the Katun River in the Altai Region (40,000 kw); one on the Terek River (40,000 kw), and one in Soviet Central Asia[19], on the Boysu irrigation canal, near Tashkent (40,000 kw).

The Plan assumed that, on average, hydropower plants would be in service for 3500 hours each year, and would produce 3.325 billion kwhr of electricity, thus reflecting a yearly saving of more than 3 million tons of unit fuel* . The high cost usually connected with the transportation of fuel over large distances, would also be saved.

Bearing in mind the total installed capacity of Soviet plants in 1921 (1228 Mw) the figures of the GOELRO Plan were impressive.

Apart from electrification, the Plan envisaged the development of navigable waterways: Astrakhan' — Petrograd, Kiev — Kherson, etc.

Lenin's principle of national location of industry found scientific substantiation, and concrete expression in the GOELRO Plan, which provided for the shift of industrial development to the East-Ural Region, Siberia, Kazakhstan, Soviet Central Asia, etc.

The Plan gave the first comprehensive evaluation of waterpower engineering — an entirely new branch of power engineering — and laid the foundations for the creation of a unified power system.

Apart from concrete directives for the construction of the above-mentioned power plants, the Plan contained the outlines for the construction of plants on the following rivers: Tuloma, Niva, Kovda, Vyga, Suna, Ufa, Belaya, Terek, Samur, Rion, Sevan, Ulba, Bukhtarma, Syr Darya, Angara, etc. Most of these ideas have been (or are now being) translated into fact.

The members of the GOELRO Commission did not overestimate the value of their work; they were fully aware of the difficulties, errors, etc.[20, 21].

Lenin was not only the initiator of the electrification plan, he was also the organizer of its implementation.

On his initiative, in October 1921, the VIII All-Russian Electrotechnical Conference was convened, with the basic aim of checking the Plan figures[22].

The GOELRO Plan formed the basis for all subsequent plans for the industrial development of the USSR[23] .

The practical realization of the Plan was a permanent consideration of the Communist Party and the Government[24].

By 1926, implementation of schedule A of the GOLERO Plan (reconstruction of existing electric power plants and equipment) was completed. The total capacity of the plants had been increased to 1,586 Mw. The first large hydropower plant in the USSR — the Volkhov HEP — was commissioned and named after V.I. Lenin[25].

The installed capacity of this new plant — 58,000 kw — exceeds by almost 11 times the total capacity of all Tsarist power plants. Lenin, at this time already seriously ill, gave his constant attention to the construction of this

* [Unit fuel: a theoretical fuel with a calorific value of 7000 kcal/kg.]

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plant. In his paper "Quality before Quantity" [literally "Better Less but Better"] he mentions this plant[26].

The first hydropower plant ever built in Central Asia, the Bozsu HEP, was put into operation on 1 May, 1926, and was followed by the commissioning of 15 other even larger plants, forming the Chirchik-Bozsu cascade. The Bozsu Plant was the first in the USSR in which automation and remote control were used to replace manual operation[27].

During 1927, the increment in the capacity of power plants (112,000 kw) was almost twice the power of the Volkhov Plant. In this year the first large hydropower plant — the Zemo-Avchaly HEP — was put into operation, and started to supply electricity to the capital of Georgia. The construction of this plant (also named after Lenin) started almost simultaneously with the Volkhov HEP[28].

In the same year the cornerstone was laid of Europe's largest power plant — the Dnieper HEP.

In 1932, only five years later, the construction of the plant was completed, and it started to supply more power than all the Tsarist plants together had provided.

In 1930, Soviet power engineers achieved the greatest annual increment in installed capacity — 598,000 kw.

The target figures of the GOELRO Plan were achieved ahead of schedule — after ten years. During this decade, the installed capacity of hydropower plants increased by a factor of 7, and the output, by a factor of 55.

In 1935, the last year of the Fifteen-Year Plan, the target figures for the construction of electric power plants were exceeded by as much as 2.5 times. In this year the total installed capacity of hydropower plants reached 896,000 kw. By the end of 1936 the Dnieper HEP had a power of 436,000 kw, and produced 10% more electricity than all the Tsarist plants (of 1913) taken together.

Lenin was deeply interested in the development of power systems. Investigations into the utilization of the huge power potential of the Volga had started as far back as the early twenties. The Second World War interrupted these studies. In 1950, the Council of Ministers of the USSR adopted a decree which called for the construction of the Volga HEP at the town of Kuibyshev.

The Volga HEP, commissioned 40 years after the October Revolution, was named after V.I. Lenin. This huge plant exceeds by more than 500,000 kw the total power of all the 30 plants included in the GOELRO Plan.

Summing up the results of the first efforts in electric-power construction, Lenin said: "12,000 kw is only a modest start. Maybe some foreigners, knowing the level of American, German, or Swedish power generation will smile at these figures. Let them smile. He who laughs last, laughs best"[29]. These prophetic words came true.

In 1960, Senator Frank E. Moss, speaking at the Conference of the National Association for Rural Electrification [in the U.S.A.] said that, although the Russians had been dealing with water-power problems for only 30 years, they had surpassed many countries in the rapid development of hydropower. They had carried out their program with remarkable energy and had put up hydropower installations at much faster rates than had been achieved in the U.S.A.[30].

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NOTES

[1]Leninskii sbornik (Collection of Lenin's Writings), Vol. XIX, pp. 34-35, Partizda, Moskva. 1932.

[2]Lenin, V.I. Sochineniya (Works), Vol. 5, p. 126.

[3]Ibidem, p. 138.

[4]Lenin, V.I. Sochineniya (Works), Vol. 27, p. 228

[5]Ibidem, p. 289.

[6]Krzhizhanovskii, G. Velikii Lenin (The Great Lenin), pp. 66-67.— Gospolit izdat. 1956.

[7]Tsentral'nyi Gosudarstvennyi Arkhiv (Central State Archives), F. 2263, Op. 1, File 74, Sheet 410.

[8]Izvestiya Elektrotresta, No. 2, p. 7. 1920.

[9]Krasnyi Arkhiv, Vol. 5, pp. 60-61. 1939.

[10]Lenin, V.I. Sochineniya (Works), Vol. 32, p. 296.

[11]Nesteruk, F. Pioner sel'skokhozyaistvennoi elektrifikatsii (K 25-letiyu Volokolamskoi GES "V pamyat Il'icha") (A Pioneering Project in Rural Electrification (the 25 Anniversary of the Volokolamsk HEP) Dedicated to the Memory of Lenin).— Gidrotekhnicheskoe Stroitel'stvo, No. 2, p. 13. 1946.

[12]Lenin, V.I. Sochineniya (Works), Vol. 30, p. 310.

[13]Plan elektrifikatsii Rossii (Plan of Electrification of Russia), p. 8, Moskva. 1920.

[14]Lenin, V.I. Sochineniya (Works), Vol. 31, p. 482.

[15]Lenin, V.I. Sochineniya (Works), Vol. 33, p. 143.

[16]In his directives to the GOELRO, Lenin outlined the geographical boundaries of the Plan, which would cover all present-day Soviet Russia, together with the Caucasus — the latter was to be included only with the agreement of the local authorities ("Krasnyi Arkhiv", Vol. 4(95), p. 40. 1938).

[17]Plan elektrifikatsii RSFSR (Plan of Electrification of the RSFSR), p. 75, Moskva. 1920.

[18]Plan elektrifikatsii RSFSR (Plan of Electrification of the RSFSR), p. 198 Moskva. 1920.

[19]The plan also provided for the construction of the Farkhad HEP, with a capacity of 18,000 kw, intended as a source of power for the Turkestan Region. This HEP — the largest in Uzbekistan — was completed in 1948.

[20]Plan elektrifikatsii Rossii (Plan of Electrification of Russia), p. 5.

[21]Ibidem.

[22]Lenin, V.I. Sochineniya (Works), Vol. 33, pp. 139-140.

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[23]Direktivy KPSS i Sovetskogo pravitel'stva (Directives of the CPSU, and of the Soviet Government), Vol.I, p.375.— Gospolitizdat. 1957.

[24]KPSS v rezolyutsiyakh (Resolutions of the Communist Party). Part II, p.13. 1954.

[25]Krzhizhanovskii, G. Sochineniya (Works), Vol.I, p.292, Moskva. 1933.

[26]Lenin, V.I. Sochineniya (Works), Vol.33, p.459.

[27]Plan elektrifikatsii Rossii (Plan of Electrification of Russia), p.648, Moskva. 1955.

[28]Lenin, V.I. Sochineniya (Works), Vol.32, p.297.

[29]Lenin, V.I. Sochineniya (Works), Vol.32, p.470.

[30]Pravda, 28 February, 1960.

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Chapter II

HISTORICAL REVIEW OF THE STUDY AND EVALUATION OF THE WATER-POWER RESOURCES OF THE USSR

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The Soviet Union has almost unlimited water-power resources. There are more than 108,000 rivers, each with a drainage area exceeding 100 km^2. The total number of rivers is close to one million, with a total length reaching almost 2,500,000 km (see Table 3).

TABLE 3

Longest rivers of the USSR and the world

Name of river	Country	Average annual discharge m^3/sec	Annual runoff billion, m^3	Watershed area, km^2	Length, km
Amazon	Brazil	100,000	3,100	7,050	6,480
Congo	Congo	50,000	1,580	3,690	4,700
Yangtze	Chinese People's Republic	36,000	1,940	1,830	5,590
La Plata	Agentine	25,000	790	3,104	4,700
Mississippi	U.S.A.	18,000	570	3,246	6,730
Yenisei	USSR	17,400	548	2,707	5,940
Lena	USSR	15,500	438	2,420	4,710
Ganges	India	14,100	440	1,060	2,700
Ob	USSR	12,500	394	2,950	5,569
Brahmaputra	India	12,000	380	670	2,900
Amur	USSR	11,000	346	2,055	4,367
Volga	USSR	8,100	251	1,459	3,694

Note: The mean annual runoff of all the rivers of the world is estimated to be 36,300 km^3.

Of the seven largest rivers of Asia, four (the Yenisei, Ob, Lena, and the Amur) flow through the USSR. Of the six largest rivers of Europe, five (the Volga, Dnieper, Kama, Don, and Pechora) are in the USSR.

The Yenisei River has the largest discharge of all Soviet rivers (17,400 m^3/sec), and is followed by the Lena River (15,500 m^3/sec). The Ob River has the largest watershed — 2,950,000 km^2. The Yenisei and Ob rivers are the longest in the USSR (5940 and 5569 km, respectively).

The entire river system of the USSR may be divided into four principal basins, with the largest of them — the basin of the Northern Arctic Ocean-covering more than half the territory of the Soviet Union. The inland noneffluent river basin of the Aral and Caspian seas covers about 25% of the total Soviet river-basin area, the Pacific-Ocean Basin 15%, and the Atlantic-Ocean Basin (the Black and Baltic seas) 8%.

The available energy of a river depends on its discharge and head[1]. The great diversity of runoff found in the territory of the USSR is seen from Table 4.

The total annual runoff of Soviet rivers is huge — 4000 km^3 — a quantity sufficient to fill the Sea of Azov four times. The map of Figure 5

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TABLE 4

River runoff from the territory of the USSR

River basins	Watershed area		River runoff		
	thousands of km^2	% of total	m^3/sec	$km^3/year$	% of total
Basin of the Arctic Ocean	11,700	51.0	76,000	2,394	61
Basin of the Pacific Ocean	3,200	15.0	27,000	850	22
Basin of the Aral and Caspian seas .	5,700	26.0	12,000	378	9
Basin of the Atlantic Ocean (Baltic and Black seas)	1,800	8.0	10,000	316	8
Total	22,400	100	125,000	3,958	100

gives details of river discharge in the USSR. Rivers with an average discharge of 300 m^3/sec carry about 52 % of the total runoff. The following figures give some idea of the potential of some large Soviet rivers (figures are in km^3/yr): Yenisei and Angara rivers — 548; Lena — 438; Ob — 394; Amur — 346; Volga — 251; Pechora — 129; Kolyma — 120; Northern Dvina — 111; Dnieper — 53; Amu Darya — 42; Don — 28.

Such a runoff distribution does not correspond to the development of the Soviet national economy. For a more rational way of utilizing the water resources of the USSR, it is necessary to have a more uniform distribution of the runoff over the year, and to achieve a territorial redistribution of the runoff, by diverting part of the stream flow from northern and Siberian rivers to the South, which is characterized by areas with little or no water.

A decree adopted on 9 July, 1931 by the USSR State Planning Commission called for the creation of a General Water Register of the USSR, intended to serve the needs of hydrologists and economists in their evaluation of water resources and the design of water-management works and projects. The Water Register contains data and information on seas, rivers, lakes, swamps, glaciers, ground water, etc. The standard work, Data on the Russian River System (1875-1935), published in 7 volumes, is included in the Register; in 1936, the "Hydrology Annual" (for river basins only) started to appear.

In 1948 a team of scientists, under the guidance of E.V. Bliznyak, started the publication of a water-management register. This register contains systematically arranged quantitative and qualitative data on the water resources of the USSR and on their utilization. The water-management register is subdivided into several sections: water power, transportation, irrigation, etc. In 1956 the Academy of Sciences started the publication of separate registers for each field.

In the years between 1946 and 1950 the Gidroenergoproekt Institute undertook a systematic study of the water resources of the whole of the USSR and produced figures of 420,000 Mw and 3680 billion kwhr for the power and annual energy output derivable from these resources. This is 11.4 % of the world's total hydropower potential: 3,750,000 Mw, 32,900 billion kwhr (annually) — see Table 5.

Of the 3680 billion kwhr, almost 2978 billion are associated with 1477 large rivers with a total watershed area[2] of more than 1000 km^2 — this corresponding to an installed capacity of 340,000 Mw.

These figures are of theoretical interest only, since it is clear that these resources cannot be utilized completely. Figures for practical utilizable resources are as follows: 1720 billion kwhr or 196,500 Mw of power[3]

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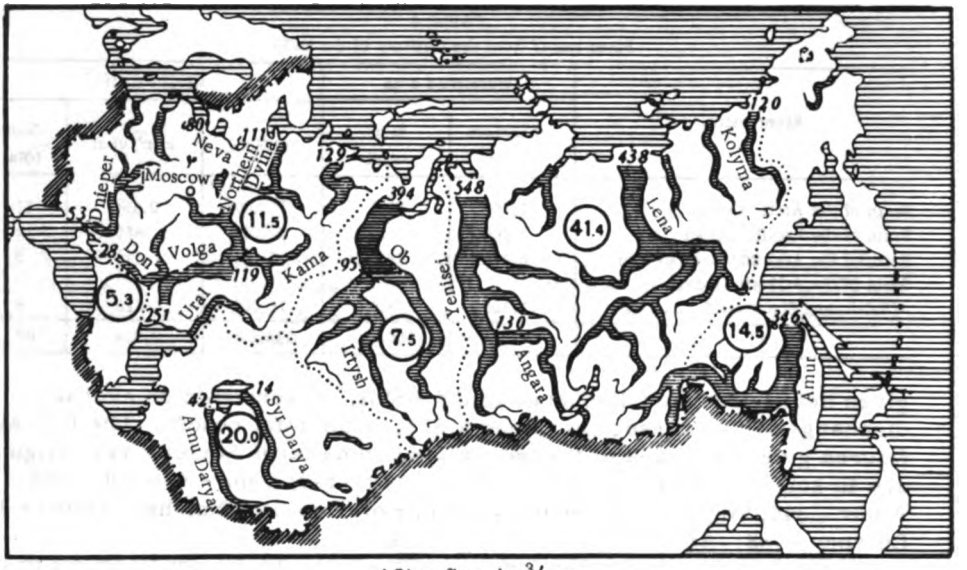
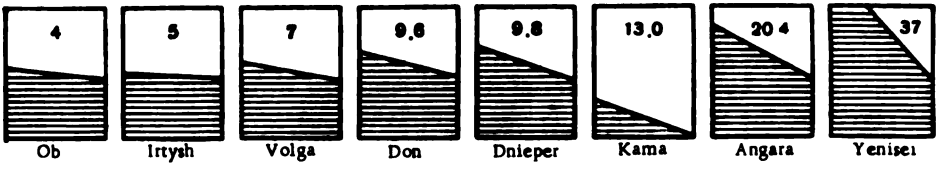


a) River flow, km^3/year



b) Mean river slope (cm/km)

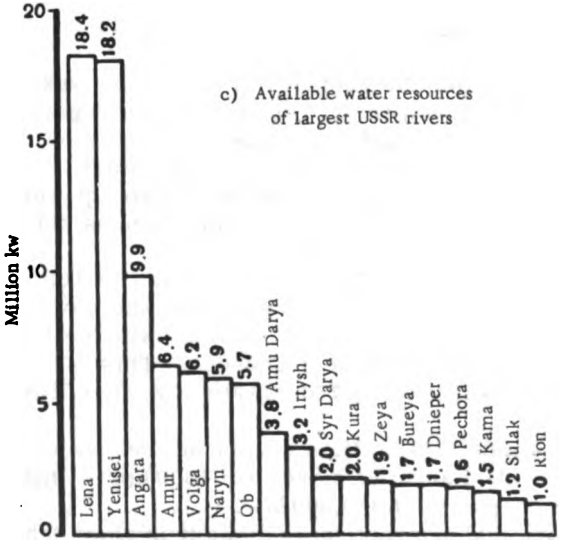


FIGURE 5. Water-power resources of the USSR (data provided by Professor A.N. Voznesenskii, 1956). (The figures in circles give the power reserves of the geographic regions indicated on the map by dotted lines, as percentages of the total Soviet reserves).

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In terms of hydropower potential, the USSR occupies first place in Europe (see Table 5), and in the whole world follows immediately behind the People's Republic of China[4].

In the USSR it is technically possible to construct 2000 hydropower plants with a total capacity of 125,000 Mw and an annual energy output of 650 billion kwhr. More carefully considered data give somewhat lower figures: 95,000 Mw produced by 1600 plants. Designs are already being worked on for 275 new plants totalling 30,000 Mw.

The fact that, in 1960, the actual capacity installed was 14,800 Mw — almost 3% of the technically exploitable potential (0.06% of the power resources of Soviet Asia)[5] — is a good sign for future power-construction prospects.

TABLE 5

Hydropower resources of various countries

Continent	Estimated reserves: million, kw	Estimated reserves: billion kwhr/year	% of total	Country	Economic potential, billion kwhr/year (tentative)	Resources as million kwhr/1000 people
Asia	1,340	11,750	35.7	World	10,000	—
Africa	700	6,150	18.7	China	2,000	3.3
North America	700	6,150	18.7	USSR	1,720	8.6
South America	600	5,250	16.0	U.S.A.	491	2.9
Europe	240	2,100	6.4	Canada	325	20.0
Australia	170	1,500	4.5	India	200	0.6
				Brazil	115	2.7
				Japan	103	1.1
Total	3750	32,900	100.0	Norway	100	29.4
				Turkey	90	5.3
				Sweden	80	10.9
Including:				France	65	1.4
USSR	434	3,800	11.5	Italy	55	1.1
China	544	4,750	14.4	Austria	40	5.7
U.S.A.	—	1,500	4.5	Argentina	32	2.5
Canada	—	1,000	3.0	Spain	32	1.3
				Switzerland	30	7.5
				German Federal Republic	16	0.3

In 1960, of all the electric power produced in the USSR, only 17.5% came from waterpower. This is 1/60 of the total power available from only 1500 large rivers in the USSR.

During the Tsarist regime, these huge power resources were not utilized; nor was an estimate made of their full extent.

After the revolution, the first study of the potential power resources of Russia was started in the twenties, under the guidance of the Commission for the Study of the Production Forces of the USSR (KEPS).

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During the period between 1933 and 1936, the Academy of Sciences of the USSR published the first Atlas of Power Resources of the USSR, which gave a power evaluation of 647 rivers. In 1938 revised figures gave a potential of 279,955 Mw.

After World War II, the Gidroenergoproekt started a special study[6] on the potential power resources of the USSR. Later work of other institutes dealt mainly with various schemes of river utilization, etc.

The available waterpower resources were calculated by the formula: $N_{kw} = 9.81QH$, where H = gross head of a river over the given stretch in meters; Q = average discharge through the stretch, in m^3/sec.

Starting in 1934, the year in which the first World Power Conference took place, various agencies began to give more attention to the evaluation of the world's power potential, but there is still no unified method for such an evaluation.

Tables 6 and 7 present data on the estimated hydropower resources of the USSR.

TABLE 6

Hydropower resources of the USSR (1956)

Republic	Area, thousand km^2	Power potential			Specific power potential, $kwhr/km^2$ of land area
		Mw	billion kwhr	% of total	
RSFSR	16,922.0	248,125	2,173.5	73.0	128.4
Tadzhik SSR	142.6	26,845	235.2	7.9	1,649.1
Kirghiz SSR	196.9	15,224	133.4	4.5	677.3
Kazakh SSR	2,753.8	15,063	131.9	4.4	47.9
Georgian SSR	76.2	11,116	97.4	3.3	1,277.9
Uzbek SSR	407.5	7,137	62.5	2.1	153.4
Ukrainian SSR	576.6	5,046	44.2	1.5	76.6
Azerbaidzhan SSR ..	85.7	3,828	33.5	1.1	391.3
Turkmen SSR	484.8	2,702	23.7	0.8	48.8
Armenian SSR	29.8	1,679	14.7	0.5	493.6
Karelian SSR ...	178.5	1,118	9.8	0.3	54.9
Byelorussian SSR ..	207.6	636	5.6	0.2	26.8
Latvian SSR	64.5	611	5.4	0.2	83.0
Lithuanian SSR ...	65.2	436	3.8	0.1	58.6
Moldavian SSR ...	33.8	366	3.2	0.1	95.2
Estonian SSR	45.1	68	0.6	0.1	13.2
USSR	22,270.6	340,000	2,978.4	100.0	133.7

It can be seen from Table 6 that 73% of all the hydropower resources of the USSR occur in the territory of the RSFSR. Tadzhikistan occupies first place with 1,649,100 $kwhr/km^2$ against an average figure for the whole of the USSR of 133,700 $kwhr/km^2$.

The data of Table 7 and Figure 5 show that more than 4/5ths of the All-Union resources are concentrated in the eastern regions of the Soviet Union (Eastern and Western Siberia, the Far-East Region, Soviet Central Asia, and Kazakhstan). The most important hydropower region of the country is Eastern Siberia, which possesses 54% of the potential resources of the whole of the USSR and exceeds the potential resources of the U.S.A., Canada, France, and the German Federal Republic together (see Table 8). The two largest rivers of Siberia alone — the Yenisei and

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the Lena — represent more than 42 % of Siberia's potential. The potential of the Angara River exceeds the potential of the Volga, Kama, Dnieper, and Don together.

TABLE 7

Hydropower resources of the economic regions of the USSR

Region	Area, thousand km²	Hydropower potential			Practically exploitable energy resources		Share of hydropower in total power supply, %
		thousand kw	billion kwhr	% of total	thousand kw	billion kwhr	
North-West	488.1	3,589	31.4	1.1	2,400	21	36.8
North	1,146.2	6,614	57.9	1.9	2,850	25	15.0
Central area	983.1	3,720	32.6	1.1	1,710	15	
Volga area	480.4	6,456	56.6	1.9	4,910	43	41.5
Ural Area	384.3	5,009	43.9	1.5	2,170	19	
Northern Caucasus	760.2	11,291	98.9	3.3	4,576	40	34.3
Western Siberia	2,423.6	24,132	211.4	7.1	14,840	130	5.1
Eastern Siberia	7,410.2	140,815	1,233.5	41.4	91,320	800	19.9
Far East	2,915.1	47,586	416.8	14.0	28,540	250	34.4
West	398.2	1,782	15.7	0.5	1,140	10	33.9
South	610.4	5,412	47.4	1.6	2,170	19	8.0
Transcaucasia	191.7	16,623	145.6	4.9	7,310	64	78.5
Soviet Central Asia	1,231.8	51,908	454.8	15.3	25,680	225	51.4
Kazakhstan	2,753.8	15,063	131.9	4.4	6,850	60	
Total	22,270.6	340,000	2,978.4	100.0	196,460	1,721 (including 1,465 billion kwhr for the Asian areas	20.4 (average)

From preliminary calculations it can be seen that power plants on the Yenisei and Angara rivers could furnish 170 billion kwhr, i.e., more than the total power output of the USSR in 1955. Other rivers of the USSR are also potential power sources (Table 8). The Syr Darya, Amu Darya, Chirchik, Zeravshan, etc., can provide more than 450 billion kwhr annually. The mountain rivers of the Caucasus can supply more than 145 billion kwhr a year. The rivers of the East-European part of the USSR can supply 241 billion, those of the Northern Caucasus and the lower Don — 98 billion, and the Ural rivers 44 billion kwhr.

By comparing the tables on the distribution of hydropower resources in the USSR with the distribution of industry, we easily see the discrepancy between the two. While the centers of basic industry are in the Ural Area, Donbass(Ukraine) and, to some extent, in Siberia, the most important hydropower resources are concentrated in the eastern regions of the country. Of the large hydropower resources listed in Table 7, about 80 % are concentrated in Siberia and the Far East Region, about 15 % in Soviet Central Asia, and only 5 % in the European part of the USSR. The eastern regions, particularly Siberia, possess 75 % of all the Soviet coal reserves, 80 % of the timber, large ore deposits, minerals, etc.

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TABLE 8

Hydropower potential of Soviet rivers

River	River basin	Hydropower potential, thousand Mw
Lena	Laptev Sea	> 20
Yenisei	Kara Sea	18.2
Angara	Yenisei	14.0
Amur	Sea of Okhotsk	> 10*
Volga	Caspian Sea	11.8
Indigirka	East-Siberian Sea	6.2
Naryn	Syr Darya	5.9
Pyandzh	Amu Darya	5.8
Ob	Kara Sea	5.7
Aldan	Lena	5.5
Vitim	Lena	5.4
Kolyma	East-Siberian Sea	5.2
Lower Tunguska	Yenisei	4.2
Khatanga	Laptev Sea	4.1
Vakhsh	Amu Darya	4.1
Olekma	Lena	4.0
Amu Darya	Aral Sea	3.8
Katun	Ob	3.7
Irtysh	Ob	3.2
Bartang	Amu Darya	2.4
Vilyui	Lena	2.4
Syr Darya	Aral Sea	2.0
Kura	Caspian Sea	2.0
Zeya	Amur	1.9
Bureya	Amur	1.7
Dnieper	Black Sea	1.7
Pechora	Arctic Ocean	1.6
Kama	Volga	1.5
Sulak	Caspian Sea	1.2
Rion	Black Sea	1.0
Razdan	Lake Sevan	0.6

* HEP, USSR.

This is why the utilization of the Siberian hydropower potential is of such great economic importance — a fact that was stressed by Lomonosov.

Table 7 also shows that the Soviet hydropower potential constitutes 20.4% of the total power resources available; in the U.S.A. hydropower forms only 7% of the total power potential.

Before concluding this chapter, a few words must be said on the harnessing of "Blue Coal" — tidal power.

In the USSR, tidal-power plants can be erected on the shores of the Arctic Ocean in the regions of the White and Barents seas, the Pacific Ocean, and the Sea of Okhotsk where, in one of the bays — Penzhina Bay — the tides reach a height of 12.3 m. A tentative figure for the power potential of tides in the USSR is 72 billion kwhr*.

* [Readers interested in tidal power are referred to the book Tidal Energy for Electric Power Plants, published by the IPST (TT 64-11028).]

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NOTES

[1] In terms of waterpower engineering, the available energy of a river depends, first of all, on its annual runoff. Thus, the Soviet Kama River is "more powerful" than the Nile. This is at first glance, a paradoxical statement but becomes understandable if we consider that the 2000 km Kama River has a yearly discharge of 119 km^3, while the 6000 km Nile has a discharge of only 98 km^3 (see Nesteruk, F. and E. Baibakov. Reki Afriki i ikh ispol'zovanie (Africa's Rivers and their Utilization)).— Rechnoi Transport, No. 8. 1961.

[2] The power potential of the 113,000 small rivers is evaluated at 66,000 Mw or 23.2% of the total power potential of the large rivers (see S. Grigor'ev. Energoresursy malykh rek SSSR (Power Resources of Small Rivers of the USSR).— Leningrad, Gidrometizdat. 1948.

[3] At the end of 1961, Gidroenergoproekt published the results of its above-mentioned study. According to the new revised data, the potential power resources amount to 3800 billion kwhr, corresponding to 434,000,000 kw of installed capacity. For 4500 rivers, the corresponding figures are: 378,000 Mw and 3300 billion kwhr. The technically achievable power potential is 240,000 Mw and 2100 billion kwhr. (Gidrotekhnicheskoe Stroilet'stvo, No. 10, p. 11. 1961).

[4] Nesteruk, F. Razvitie gidroenergeticheskogo stroitel'stva v KNR (Development of Water Power in China).— In: Sbornik "Iz istorii nauki i tekhniki v stranakh Vostoka", No. 2, p. 12, Moskva. 1961.

[5] At present [i.e., the date of publication of this book in Russia] the actual percentages of utilization of power potential in various countries are as follows: Europe (total) 40. Breakdown by countries: Italy — 70.5; Switzerland — 62.3; France — 52.3; German Federal Republic — 51; Sweden — 37; Austria — 30, Norway — 29.3; Canada — 48.5; U.S.A. — 28.8; Japan — 67 (see Figure 72).

[6] Voznesenskii, A, et al. Gidroenergeticheskie resursy SSSR (The Hydropower Resources of the USSR).— Gidrotekhnicheskoe Stroitel'stvo, No. 4. 1956 and No. 11. 1957.

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Chapter III

THE DEVELOPMENT OF HYDROPOWER IN THE USSR (HISTORICAL REVIEW)

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THE PERIOD OF ECONOMIC RECONSTRUCTION AFTER THE REVOLUTION AND CIVIL WAR (1918-1927)

As mentioned in the previous chapter, soon after the revolution, the Soviet Government, under the guidance of Lenin, initiated the design and construction of new power plants and the reconstruction of those destroyed or forced to stop operation during the revolution and civil war. A special agency was created — the Management Agency for Electric Construction, abbreviated to "Elektrostroi". This agency was responsible directly to the Supreme Council of the National Economy (VSNKh).

A special conference of the VSNKh, called by Lenin on 22 March, 1918, adopted a decision to start preparatory work for the construction of the Volkhov Hydroelectric Plant, the design of which was ready before the revolution broke out.

One month later, on 22 April, 1918, the Council of People's Commissars discussed the construction of hydropower plants on the Volkhov, Svir', Imatra, and some other rivers.

At this conference, Lenin fixed the power requirements of Petrograd industry at 250,000 hp. The power actually used at the time was 130,000 hp.

The official decision of the Government to construct the Volkhov HEP came on 13 June, 1918. The plant was intended to have a capacity of 58,000 kw.

At that period, the construction of such a high-capacity plant in the USSR was not an easy undertaking. The chief engineer of the project, G.O. Graftio, has drawn attention to the assistance which was given by Lenin in the realization of this project[1].

Construction started in 1919 and gathered momentum only during the autumn of 1921, after the energetic intervention of Lenin[2].

"The period during which the Volkhov Plant was planned and constructed was a period of civil wars and economic chaos. It required extraordinary efforts on the part of the people and marked a new stage in the development of the Country"[3].

Before the first Five-Year Plan had been drawn up, in addition to the construction of the Volkhov HEP, the design and construction were started of twelve other HEPs, totalling 648 Mw (see Table 9).

By the beginning of 1923, of the 30 regional power plants envisaged by the GOELRO Plan, eight were already under construction. At the same time, the construction of the Volkhov HEP continued. M.I. Kalinin, who had arrived at the Volkhov HEP site, wrote in 1924: "The plant must be finished on time whatever happens. This is a question of honor"[4].

The XIV Party Conference, held in December 1925, reviewed the implementation of the GOELRO Plan. During the years 1921 to 1925, the

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total power of plants in operation amounted to 152 Mw. The so-called "A" Program of the GOELRO Plan was completed in 1926; it covered the reconstruction and modernization of existing power plants. In the same year, a number of new plants, totalling 186 Mw, were commissioned. In the thirteen years 1913 to 1926, the output of electricity doubled. The Volkhov HEP was put into operation in December 1926 (official date 19 December, 1926).

The plant, with its eight turbine units, started full operation in the summer of 1927[5]. The annual design output of the Volkhov HEP was 356 million kwhr (cf. the output of 200 plants which, in 1916, produced together 480 million kwhr).

"The importance of the construction of the Volkhov HEP lay not only in its contribution to the general raising of the industrial power of the north-western region, but also in the fact that it disproved the widespread opinion (among the enemies of the USSR) that the fultilment of the electrification plans, developed under Lenin's direct guidance, was impossible"[6].

TABLE 9

Hydroelectric power plants built immediately after the war

Name of plant	Year		Power, Mw
	start of construction	commissioning	
Volkhov	1921	1926	58.0
Zemo-Avchaly, Georgia	1922	1927	36.8
Bozsu, Uzbekistan	1923	1927	4.8
Yerevan No.1, Armenia	1923	1926	7.8
Yerevan No.2, Armenia (automatic control)	1930	1932	2.4
Kondopoga on the Suna River	(1917) 1923	1928	5.4
Pervomaisk on the Southern Bug	1925	1929	1.2
Upper-Khariuzovskaya, Altai	1925	1927	3.0
Leninakan (Shirakskii irrigation canal) Armenia	1925	1928	5.3
Syzran' on the Syzranka River	1925	1926	2.3
Gizel'don, Northern Ossetia	1927	1936	21.8
Rion, Georgia	1927	1933	48.0
Lower-Svir'	1927	1933	100.0
Dnieper im. Lenin	1927	1932	558.0
Penza on the Sura River	1925	1928	1.5

At that time, a favorite theme of the enemies of the USSR was the construction of the Volkhov HEP and its initial failures. Thus the German "Elektrische Zeitung" wrote: "It is hard to see in the report of the GOELRO Commission, anything other than the product of a strong imagination"[7].

The annual utilization of the plant (5500 hours) exceeded by a factor as high as 1.5 to 2 the figures for foreign power plants erected later than the Volkhov HEP.

The Volkhov HEP was the first project set up on a large river with heavy ice drift. This was the first instance of erecting a dam on a relatively weak foundation, necessitating the injection of a large quantity of grout for

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the reinforcement of the foundation. The total length of the water-retaining structures exceeded 400 m. The earth work amounted to 730,000 m^3, the mass and reinforced concrete to 340,000 m^3, and the steel structures to 8000 tons. The construction of the plant required 14 million man-days.

"These facts and figures are insufficient to give a proper impression of the work done in the construction of the Volkhov HEP. The harnessing of the northern rivers marks a new epoch in the development of our production forces; the project is a new victory in the fight with nature"[8].

The Volkhov HEP started to operate in 1926. In the same year, the Yerevanskaya No. 1 Plant in Armenia was commissioned. This was the first plant in the chain of hydropower stations of the Sevan-Razdan cascade system. In the same year, the Bozsu Plant near Tashkent was completed on an irrigation canal fed from the Chirchik River. The Zemo-Avchalskaya (ZAGES) Plant im. Lenin — the first diversion-type plant — was commissioned in 1927.

The ZAGES Plant was built in only three and a half years. The amount of earthwork involved was 500,000 m^3 and the concrete work (including concreting of foundations, etc.) 460,000 m^3.

Although, in general, these plants were built using the equipment available from before the revolution, some new equipment was provided to help in mechanizing the work. Thus, at the dam of the ZAGES Plant, a cable crane was assembled using materials and equipment available on the site.

The whole country contributed to the rapid construction of the Volkhov HEP. Thus, the Leningrad "Elektrosila" Plant supplied the generators[9], the caissons came from the Ukraine, the steel from Siberia, and miscellaneous electrical equipment was furnished by Moscow and Leningrad plants.

The builders of the Volkhov Plant used the latest developments in mechanization, developments which subsequently became current practice in power construction. Among the excavators used on the site was a large steam excavator built by the Putilov Works. This was a rail-mounted crane equipped with a 2.5 m^3 bucket. Many engineering problems connected with the construction of the plant were successfully solved. The excavation site was surrounded by coffer-dams made of high cribwork of Russian and of frame-type installed on the boulder-strewn river bottom. The dam foundation, over a length of 100 to 150 m, was injection-grouted. Both dam faces, the screen-house walls, and all the interior walls of the scroll case and draft tubes were gunited. Large shaped forms were used for the concrete draft tubes. For the first time in Soviet practice, the spilling nappe from the headrace was connected with the tailrace by a nonsubmerged hydraulic jump. This type of jump was subsequently used, not only for dams on rock foundations, but also for dams on soft soil (cf. the Nizhne-Svirskaya HEP dam). The upturned bucket of the spillway section of the dam is connected with the tailrace through a massive concrete apron.

The upturned bucket, part of the apron, and the whole spillway were lined with granite slabs laid on a layer of crushed stone. This layer rested on a concrete base. All these elements were bonded with mortar pumped in through a pipeline. An attempt was made to speed up construction work by using 48 caissons for underwater work of a type currently employed in bridge and harbor construction. These were adopted for use in hydropower constructions. However, the use of caissons under these conditions proved a failure.

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Much controversy arose among engineers over the problem of selecting the voltage level for the Volkhov-Leningrad transmission line (length 130 km). The more cautious ones held that, under Soviet climatic conditions, a voltage higher than 40 kv would be dangerous. Others went so far as to recommend 150 and even 180 kv. The problem was complicated by the fact that there was no possibility of learning from American and European practice. After much discussion, it was decided to use a tension of 110 kv. This decision was based on advice given by the staff of the St. Petersburg Polytechnic Institute. Soviet plants successfully coped with the task of designing equipment for such a voltage. The Sevkabel' Plant supplied a 35 kv underground cable of novel design, used abroad only much later.

The foreign press praised the feats of engineering achieved in the construction of the Volkhov HEP[10].

Other hydropower projects were carried out concurrently with the construction of the Volkhov HEP: completion of the Kondopozhskaya HEP on the Suna River (construction had stopped in 1917); harnessing the water of the Shiraka Irrigation Canal in Armenia for power generation; construction of power plants on the Southern Bug (Pervomaiskaya HEP) on the Syzranka River (Syzranskaya HEP), on the Sura River (Penzenskaya HEP), and on the Gromotukha River in the Ulba River Basin, Altai Region (Khariuzovskaya HEP).

The successes of Soviet power construction during the period from 1913 to 1928 are shown below.

In 1928 the total installed capacity of USSR power plants was 1905 Mw, i.e., twice as high as in 1913. During the period from 1913 to 1918, the capacity of hydropower plants increased from 16,000 kw (1913) to 121,000 kw (in 1928). Power production in this period reached 5 billion kwhr, including 430 million kwhr in hydropower plants. In 1928, the length of 35-110 kv lines reached 203 km against 70 km in 1913. In 1928, many of the power plants were interconnected to form power systems so that the number of yearly hours of operation increased from 1770 (1913) to 2720 (1928).

In view of the low productivity level of recently set-up Soviet industry, the XV Party Conference of 1927 adopted a decision, calling for the radical reconstruction of the whole of industry. The rough outlines of the first Five-Year Plan of economic development were thus conceived.

THE PERIOD OF THE FIRST PREWAR FIVE-YEAR PLANS (1928-1941)

The first Five-Year Plans transformed the USSR from a backward agrarian country into a technically advanced industrial power.

During the first and second plans construction was started on more than 32 large power plants, among them the pioneering project — the Dnieper HEP im. Lenin; the Nizhne-Svirskaya Plant im. Graftio; the Rionskaya HEP; the high-head hydropower plants, Gizel'donskaya, Gergebil'skaya, Dzoragetskaya, and many others.

The third Five-Year Plan saw the construction of Uglich HEP (commissioned in 1940) and Rybinsk HEP (completed in 1941), both on the

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Volga; two large HEPs, the Komsomol'skaya and Tavakskaya plants (1940-1941) on the Chirchik River, etc.

Two remarkable projects of the prewar plans deserve particular mention: the Baltic-White Sea Canal (1931-1933) and the Volga-Moskva Canal im. Moscow (1932-1937). These canals are navigable and are also used for power generation.

The construction of large thermal and hydropower plants markedly improved Moscow's power supply. This fact was of the utmost importance during World War II. By 1939, the capacity of Moscow's generating plants had increased by as much as 16 times compared with 1913, while the energy output had increased by 20 times.

On the eve of World War II, Soviet power plants were producing 48.3 billion kwhr annually, i.e., 25 times more than that produced in 1913. The total installed capacity had increased to 11,200 Mw.

The annual per capita consumption of electricity markedly increased during the period between the two wars to 250 kwhr against 8 kwhr in 1913.

Each newly erected power plant was a further step in the development of Soviet power engineering. The experience gained in the construction of the famous Dnieper HEP was very useful in the building of other plants. Thus, the dams of the Lower-Svir' HEP were the first in the world to be erected on clayey soil. The Gizel'donskaya HEP is remarkable for its dams which create a head of several hundred meters. The Gergebil'skaya HEP was the first in the USSR to be equipped with dams of the combined arc-gravity type. The Dzoragetskaya HEP was equipped with roller gates of the self-rolling type. The dam of the Ivankovo HEP on the Upper Volga was built by the hydraulic-fill method using sand sluicing. The Uglich and Rybinsk HEPs, both built on clayey soil, have novel dams in which reinforced-concrete facing shells were extensively used. The dams were hydraulically filled during winter, using river sand. The station was equipped with large Soviet-built turbines of a unique design. The construction of the White Sea-Baltic Sea Canal involved the erection of 128 hydrotechnical structures of various types, many of them incorporating novel wood elements.

The total power of the hydroelectric plants put into operation within the framework of the prewar Five-Year Plans exceeded the power of the Tsarist hydroelectric plants almost 200 times.

The construction of large hydropower plants favored the regulation of runoff and the creation of large storage reservoirs, and improved river navigation, particularly on the Upper Volga, Dnieper, Volkhov, Svir', and Moskva.

THE FIRST FIVE-YEAR PLAN (1928-1932)

The first Five-Year Plan, adopted by the XVI Party Conference in 1929, contained a detailed outline of power-engineering construction. According to the target figures, which were based on GOELRO-Plan data, toward the end of the first Five-Year Plan, the production of energy was to increase from 5 billion kwhr to 22 billion kwhr[11]. Capital investment for power-engineering construction during the first plan was to be 3.1 billion rubles. During the previous five years, 900 million rubles had been invested). During the period from 1928 to 1932, the consumption of electricity was to

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rise from 2.9 billion to 7.2 billion kwhr. Accordingly, in 1930, a decision was adopted to fulfill the target figures of the Five-Year Plan in four years[12].

The first Five-Year Plan had a strong effect on the completion of the Dnieper HEP, which had been started in 1927 with a planned capacity of 650,000 hp[13].

The official opening ceremony of the Dnieper HEP took place on 10 October, 1932[14].

"The Dnieper Plant, at its time the most powerful plant in Europe, and only slightly below the level of American hydroelectric plants, was of paramount importance to the industrialization of the USSR"[15] (B.E. Vedeneev).

Nine turbine units of 62 Mw each, gave a station capacity of 558 Mw. The turbines installed at the Dnieper HEP were of unique design and construction; in capacity, each of them far exceeded the total power of the largest Tsarist hydroelectric plant (50 Mw).

The dam of the Dnieper Power Plant had a length of 760 m, a height of 62 m, and a width of 44 m. The dam, which created a head of about 38 m, was of semicircular shape, thus increasing the effective spillway length. The spillway part of the dam consisted of 47 bays, each covered by a 9.7 × ×13.6 m gate weighing 80 tons. The dam was designed for a peak discharge of 25,000 m^3/sec. It created a reservoir with a storage volume of 1.1billion m^3 (2.1 % of the annual runoff). The dam ensures seasonal regulation of the river flow (annual river discharge 25,000 m^3/sec).

The three-stage river lock of the Dnieper HEP (13.5 m head) and the forebay created by it are still the largest in the USSR[16].

The Dnieper HEP supplied current at a voltage of154 kv — long considered impractical. At the same time that the Dnieper HEP was being put up, the Dnieper integrated works for the production of aluminum, magnesium, and ferroalloys, and the Zaporozhe Iron and Steel Works were being built. In 1940, the Dnieper HEP started to export electricity over 220 kv transmission lines. The first ten lines had a total line-length of 1000 km, and covered an area which spread up to 300 km.

In terms of construction techniques and equipment, the Dnieper HEP was, at its time, among the most advanced projects in the world.

The project involved the solution of complex problems connected with the harnessing of the Dnieper River[17].

In an eight-month period in 1930, 518,000 m^3 of mass concrete were placed: 110,000 m^3 were placed in October alone, thus exceeding by a big margin the world record of 85,000 m^3, established in June 1930 in the construction of the Bagnell HEP in the U.S.A.[18]

The construction of the Dnieper HEP involved the following: earth moving — 3.4 million m^3; rock excavation — 1.9 million m^3; concrete placing — 1.2 million m^3; erection of cribwork cofferdams, with a total length of 3000 m; erection of 26,500 tons of steel structures. Despite the amount of work, the construction was completed in an extremely short period — 1500 working days (37 man-days per kilowatt of installed capacity).

New construction techniques were used for the first time: water giants for the dislocation of the top layer from rocks and percussion drills for bore-hole drilling. The trestle work method of concrete placing (which subsequently gained wide acceptance in hydropower construction) could not be used on the Dnieper HEP project. This was mainly due to the lack of appropriate steel structures for supporting columns for the platforms.

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These structures had to be replaced by masonry. To speed up construction in the erection and installation of steel structures and hydromechanical equipment, shop-assembled units were used.

FIGURE 6. Dnieper dam and hydroelectric power plant im. Lenin

By proper work planning, much time was saved in the installation of the turbines: the first turbine unit was installed in 34 days, the second in 29 days, and the third in 26 days. At this time, American engineers were installing turbines of smaller power in 45 days.

It should be noted that the execution of the project and the work planning were carried out exclusively by Soviet engineers. Many foreign companies had been approached for help but, after detailed examination of the proposals of various foreign companies (American and German), the management of the Dnieper HEP construction agency, guided by B.E. Vedeneev, declined to accept any of the foreign proposals. These provided for a period of six years for the construction of the development. The Soviet plan envisaged simultaneous erection of the hydrotechnical structures on both river banks, and the use of cribwork cofferdams. Thanks to these measures, construction was completed in only five years.

During the construction of the Dnieper HEP, Soviet power engineers gradually acquired self-confidence, and began to show a critical approach to foreign engineering practice. Thus, the American consulting engineer, Cooper, suggested an initial installed capacity of 240 Mw. The Soviet engineers boldly decided to install 390 Mw (13 turbine units). In 1920 these initial figures were revised, and it was decided to install 558 Mw (using only nine turbine units). This involved the construction of turbines of a pioneering design — each of these nine units was rated at 62 Mw.

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The construction site of the Dnieper HEP became a true research center for power engineering; a school of advanced engineering for generations of engineers and technicians. In 1932, the year in which the power plant was commissioned, the chief engineer of the construction project, H.W. Winter, and the project designer, Professor I.G. Aleksandrov, were elected members of the USSR Academy of Sciences.

Many engineers and technicians, who participated actively in the construction of the Dnieper HEP, subsequently took part in the construction of other projects: on the Volga, Kama, Baksan, and other rivers. A large group of former Dneprostroi staff was transferred to the construction of the Chirchik power-plant cascade in Soviet Central Asia — most of these plants were of diversion-type.

In an average runoff year the Dnieper HEP produced 2.9 billion kwhr of electricity. From the time it was commissioned until World War II, the Dnieper HEP produced over 17 billion kwhr, supplying growing industries and saving the country more than ten million tons of high-grade fuel[19].

The impact of the construction and operation of the Dnieper HEP was not confined to the industrial development of the country. Navigation, water supply, irrigation and fishing were all markedly improved. The backwater created by the Dnieper Dam eliminated (by covering) the famous Dnieper Rapids, thus producing a continuous waterway from the headwaters down to the Black Sea.

During the Second World War the Dnieper HEP was completely destroyed. After the War, it was restored with only slight changes in the initial layout. This fact reaffirms the correctness of the design decisions adopted in the first plan of the station.

Apart from the Dnieper HEP, a number of smaller hydroelectric stations, totalling about 377 Mw (12.6 % of the existing station capacity) were also constructed during the first Five-Year Plan.

During this period the production of electricity increased by a factor of 3.3, reaching 13.54 billion kwhr (1932), including 812 million kwhr of hydropower — equivalent to 6 % of the total power generated.

The first Five-Year Plan created conditions for expanding the power supply in a series of Soviet Republics — Armenia, Georgia, Uzbekistan, and Tadzhikistan. Toward the end of the Five-Year Plan, 12 new hydroelectric plants were completed in various regions of the Country, i.a., three in Armenia, two in Georgia, and two in Soviet Central Asia.

TABLE 10

Hydropower plants constructed during the first Five-Year Plan

Name of station	Construction period	Power of station, Mw	Remarks
Dzoragetskaya (Armenia)	1928 — 1932	20.0	First large Soviet high-head plant
Kadyr'inskaya (Tashkent)	1930 — 1932	13.6	Second station of the town of Tashkent
Gergebil'skaya (Daghestan)	1930 — 1936	7.5	
Kanakerskaya (Armenia)	1931 — 1936	88.0	
Verkhne-Varzobskaya (Tadzhikistan)	1931 — 1936	7.2	
Chirchik Cascade (Uzbekistan)	1932 —	116.0	
Sukhumskaya (Abkhazia)	1932 — 1948	19.2	

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Among these plants we should note the Kondopozhskaya Station on the Suna River, the Leninankanskaya Plant in Armenia, the Penzenskaya and Syzran Plants (1928), and the Pervomaiskaya Plant on the Southern Bug (1929). The Yerevanskaya No. 2 Plant was put into operation in 1932.

The three Francis turbines for the Dzoragetskaya HEP, together giving 20 Mw with a head of 105 m, were built by the Leningrad Metal Works. They represent an outstanding achievement of Soviet turbine construction. The diversion tunnel of the Dzoragetskaya HEP is 2.5 km long; it has a diameter of 3.2 m and is provided with large roller gates (23 × 6.5 m), built to a design by Professor Gebeli of the Krasnyi Putilovets Plant.

Another outstanding achievement of the first Five-Year Plan was the construction, in only one year and nine months (November 1931 to August 1933), of the 227 km Baltic Sea-White Sea Canal. There are 128 hydrotechnical structures on the canal, including 19 locks and 15 dams. During this short construction period, the following work was carried out: 21 million m^3 earthwork (7 times more than at the site of the Dnieper HEP), including 2.5 million m^3 of rock excavation, 921,000 m^3 of cribwork cofferdams; and 390,000 m^3 of concrete. The canal is equipped with numerous hydrotechnical structures of novel design: wood dams and locks, buttress-type dams for a head of 8 m, wood diaphragms for earth dams, cribwork dams with concrete abutments for a head of 11 m, wood lock gates, etc. Several hydroelectric plants were erected along the canal, thus increasing its economic importance.

The first Five-Year Plan was implemented ahead of the original schedule, i.e., in four years and three months (see report by V. V. Kuibyshev to the TsK and TsKK).

In 1932 ten of the largest electric power plants, each of them with an installed capacity greater than 100 Mw — including the Dnieper HEP, with its first units producing 310 Mw — generated almost one third of all the power produced in the country. This can be regarded as an achievement of the first Five-Year Plan.

The successful fulfilment of the first Five-Year Plan had a strong impact on both power production and on the industrialization of the country. Thus, the first five turbine units for the Dnieper HEP were delivered by an American company when the other four units had already been made by the Soviet Elektrosila Works. During the first plan, the unit power of the turbines produced by Soviet plants increased from 12 Mw to 60 Mw.

In November, 1932, a writer in the American journal "Nation" said that the four years of the Five-Year Plan had led to outstanding achievements. The Soviet Union had worked with a zeal as if at war in creating the basis for a new life. The face of the country had completely changed, he continued; hundreds of new regional power plants and several giants like the Dnieper Plant had gradually made Lenin's words come true: Socialism means Soviet regime plus electrification . . . Electricity was coming to the villages. Farm hands operated agricultural machinery more complicated and larger than anything that had been built in the U.S.A. . . Russia was quickly passing from the century of rural economy to the century of iron, concrete, and machinery . . . *

Despite the remarkable successes of the first Five-Year Plan, the pace of power production lagged behind the rapid expansion of industry. Subsequent plans for economic development had, therefore, to provide for a still greater expansion of power generation.

[Retranslated from Russian.]

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THE SECOND FIVE-YEAR PLAN (1933-1937)

The second Five-Year Plan, approved and adopted by the XVII Congress of the Communist Party in January-February 1934, provided for a further increase in the industrial power of the USSR so as to ensure its complete self-sufficiency and economic independence, the final aim being to attain and surpass the economic development of the most advanced western countries.

Whereas the GOELRO Plan and the first Five-Year Plan laid particular stress on the harnessing of water power in regions lacking in conventional fuel sources, the second plan provided for the rational use of existing water-power resources of the country. During this period construction work started on the Volkhov chain of power stations and on the unique Sevan-Razdan (Zanginskii) cascade in Armenia.

During the second Five-Year Plan the Soviet Government issued two decrees of extreme importance for the development of water resources: a decree referring to the construction of the Yaroslavl, Balakhna, and Perm hydropower developments, and another decree providing for the construction of the Kamyshin Dam and HEP, and the irrigation of the Transvolga Area. These structures, by creating backwater conditions over large stretches of river upstream from the dams, and thus regulating the downstream river flow, were intended to produce a considerable increase in the navigation depth of the Volga. However, the initial project subsequently underwent some changes designed to give more efficient utilization of the river potential: the Yaroslavl project was replaced with the Rybinsk development (1935-1940); the Perm project was replaced with the Solikamsk project. The irrigation of the Transvolga Area was combined with the Kuibyshev water-management projects instead of with the Kamyshin project. These changes, however, did not alter the basic idea of comprehensive utilization of water resources as envisaged by the projects of the second Five-Year Plan.

All these projects, although developed during the period of the second Plan, were only completed during the implementation of the following plans. In what follows, we shall discuss the actual achievements in water-power engineering which belong to the period of the second Five-Year Plan.

Two hydropower projects of utmost importance were designed and completed: the Rionskaya Power Plant on the Rion River (July 1933), and the Nizhne-Svirskaya HEP im. G.O. Graftio (December 1933).

The Rionskaya HEP, equipped with four 12,200 kw Francis turbines constructed at the Leningrad Metal Works, was intended to supply electricity to the ferromanganese industry and to the electric railroads in the Transcaucasian Region. (The railroad through the Suram mountain pass was the first Soviet electric railroad.)

Lenin gave much attention to the electrification of railroads. As early as 1918[20], in his "Scientific and Engineering Projects" he stressed the importance of the electrification of industry and transportation.

Before embarking on electrification of the railroads, thorough scientific and engineering investigations and studies of power generation, engine design, electric equipment, etc., were carried out. In these studies A.A. Vul'f, G.O. Graftio, A.B. Lebedev, V.A. Shevalin, etc., participated.

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The railroad over the Suram mountain pass used direct current at 3000 v. This form of power supply was subsequently adopted for other electric railroads. In connection with the electrification of the Suram high-mountain railroad, the necessity arose of constructing a high-power transmission line. This was the ZAGES-Rion HEP 110 kv line, the first line to be put up in Georgia and one of the first lines in the USSR to be erected using metal supports. The line supplied electricity both for the railroad and for regional power supply.

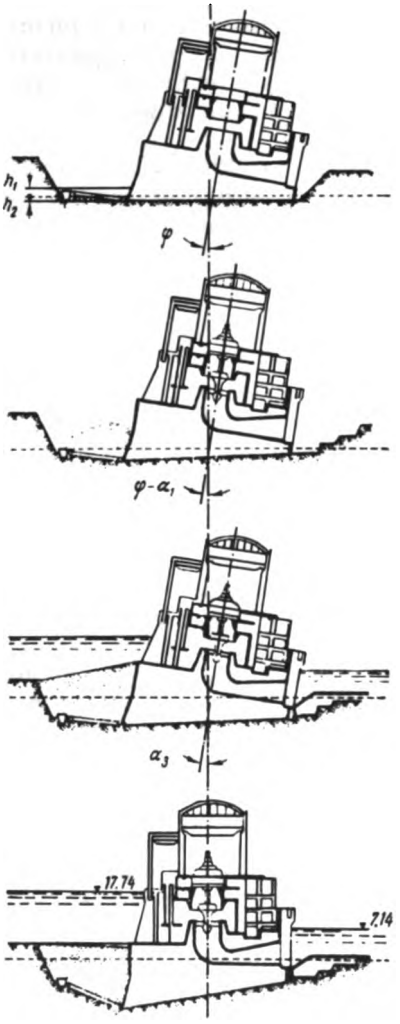

FIGURE 7. The "inclined" Nizhne-Svirskaya HEP (the figure shows intermediate stages in the settling of the powerhouse).

The Suram high-mountain electric railroad was officially opened on 16 August, 1932, a date which marked a great success for Soviet engineering[21].

The construction of the Nizhne-Svirskaya [Lower Svir] HEP, which was completed despite extremely unfavorable geological conditions (plastic clayey foundation rock), was a remarkable achievement of engineering, not only in the context of Soviet technology, but also by world standards. Although the decision to construct this power plant was adopted by the Council of People's Commissars, under Lenin's guidance, as early as 3 May, 1918, its completion had to be postponed until 19 October, 1927, due to the Civil War. The two-stage HEP had a head of 10.5 m; the headwater of the plant caused the immersion of 14 rapids.

In world power-construction practice, instances are known of the collapse of hydrotechnical structures erected on soft rock. In all cases, the composition of these rock foundations was more homogeneous than the plastic Devonian clays of the banks and bed of the Svir River. Small wonder then that Soviet hydraulic engineers, having only the experience gained during the construction of the Volkhov HEP, had to resort to foreign assistance. The Soviet Government invited many foreign experts to help in the construction of hydropower plants. One of them, the American engineer Cooper was asked to give his opinion on the construction of the plant on the Lower Svir. He did not advance any practical method for erecting the plant. On the contrary, he pointed to the danger of constructing hydrotechnical structures on such a rock foundation[22].

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The Nizhne-Svirskaya (Lower Svir) HEP has been operating for more than 25 years. The second HEP, which was later put up on the Svir to the same design, is still giving trouble-free operation after more than ten years.

Despite this advice, Soviet specialists mastered all the difficulties. With the available data on soil mechanics they were able to predict the timetable of the settling of the hydrotechnical structures. Based on a suggestion by Graftio, the rather bold decision was adopted of constructing an inclined powerhouse which, subsequently, acquired a vertical position as the head built up. The initial slope was 0.075%.

The 22 m high dam of the Nizhne-Svirskaya HEP was of novel design and had a so-called "spread" profile. Settling of the dam was 24 cm. The experience gained in the construction of dams of such a type was used in the design of spillway dams on the Volga.

The construction of the Nizhne-Svirskaya HEP involved 5 million m^3 of earthwork, 580,000 m^3 of concrete work, and the installation of an enormous number of steel structures. Some of the most difficult problems in the construction of this plant were the prevention of open-soil freezing, the prevention of soil swelling because of the presence of groundwater, and the minimizing of the settling of the structures.

Planning and mechanization of the site work were of the same high level as on the Dneprostroi site. Earthmoving was carried out by suction dredges, working down to a depth of 11 m, and by draglines equipped with 3 m^3 buckets and 38 m booms. Under the heavy-soil conditions of the Svir River, the output of this equipment (in three shifts) was between 40,000 and 50,000 m^3. For the first time cement was unloaded pneumatically from railroad cars, and loaded pneumatically into the hoppers of the construction site.

The first turbine set was commissioned on 19 December, 1933. The complete plant was put into operation on 30 September, 1935. Its installed capacity is 116 Mw and the average yearly output 600 million kwhr. This means an annual saving of more than 400,000 tons of lignite.

The plant was equipped with large (29 Mw) Francis turbines, having runners of 7.4 m diameter. The construction of the fourth turbine (by the Leningrad Metal Works) for this plant was a great Soviet achievement. Thanks to the experience gained in the construction of transmission lines, it became possible to erect lines operating at above 150 kv. The 240 km Svir'-Leningrad line was the first Soviet 220 kv line. This high voltage was (until 1955) the highest transmission voltage in use (see Figure 30).

In addition to improving power supply, the new Svir' development had a good effect on navigation on the Svir' River over its most precipitous stretches, and constituted the most important link in the White Sea-Baltic Sea canal system.

At a new session of the Communist Party, held in February 1934[23], a decision was adopted providing for more intensive use of local energy sources, particularly water power. This decision had a strong influence on the further development of HEP construction.

In 1934, the second stage of the Zemo-Avchalskaya HEP in Georgia, was commissioned, and construction started on the Ul'ba HEP, on the Malaya Ul'ba River (a tributary of the Irtysh River). This latter station was to supply power to the mining industry of the Altai Region. The Niva No. 2 HEP, in the mineral-rich Kola Peninsula in the Arctic Region, was also started at this time.

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For the first time in Soviet practice, a station — the Ul'ba HEP — was provided with a wooden diversion-channel conduit, 8 km long and 3.25 m in diameter. The rockfill dam, which is of the spillway type, has a height of 10 m and a length of 110 m. It is provided with a wooden diaphragm, designed by the Russian engineer N.P. Puzyrevskii (see Figure 55).

The rapidly expanding industry of the Kola Peninsula required a lot of electricity. In the absence of cheap local fuel, a decision was made to harness the numerous local rivers which contained many rapids. The first HEP on this peninsula, on the Niva River, was constructed in 1934. A special dam was erected on the Niva, not far from its outflow from the Imandra Lake. This gave runoff regulation of the whole Niva power-plant cascade. On the middle stretch of this river, the 45 Mw No. 2 Niva HEP was constructed.

In 1934, the USSR reached, in terms of power generation, third place in the world, surpassed only by the U.S.A. and Germany, and equalled by Great Britain and Canada (see Figure 73). In 1925, the USSR occupied 11th place. In 1934 the installed capacity of Soviet plants exceeded that of Tsarist Russia by a factor of six, the energy output was more than ten times higher than that of Tsarist Russia.

In 1931, the target figures of the GOELRO Plan were reached ahead of schedule. By 1935, these target figures had been exceeded almost three times (see Table 11).

TABLE 11a
Facts and figures of the GOELRO Plan

	1913	1920	GOELRO target figures	Level in 1935
Total industrial production as % of 1913 figures	100	13.75	180 — 200	570.8
Power of regional electric stations, Mw	117	255*	1750	4540
power from HEPs included, Mw	16	—	640 (10 HEPs)	896 (19 HEPs)
Energy output, million kwhr	1945	500*	8000 — 9000	26,294

* 1921.

TABLE 11b

	Level in 1935, as % of GOELRO target figures
Total industrial production	320
Installed power of regional plants	258.6
including HEPs	140
Energy output	330

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H.G. Wells, the famous British writer, after a visit to the USSR in 1934, wrote in his "Experiment in Autobiography": "He [Lenin] went on working, as a ferment, long after his working days had ended. He is still working perhaps as powerfully as ever".

Compared with the capacity of plants during the Tsarist period, the installed capacity of HEPs in the USSR increased by a factor of 56 and reached 896 Mw in 19 regional plants (the GOELRO Plan called for 640 Mw in 10 plants). These plants provided a yearly output of more than 3 billion kwhr,of electricity. In 1926 the HEPs' share of the total production of electric power was still extremely low (fractions of one per cent); in 1932 regional hydropower plants supplied 7.3% of the total power produced by regional plants.

During the period 1929 through 1935, the production of electric power increased from 5 billion to 25.9 billion kwhr. The annual increment was, on average twice that of Great Britain.

During that period power production in the western countries continuously dropped. Only the USSR exhibited a steady increase in power production. This fact was remarked on in the French journal "La Technique Moderne" (April 1935).

In Germany the HEPs' share in the total production of electric power dropped from 21.5% (in 1932) to 14.9% (in 1934). In the U.S.A., while thermal power plants increased their production from 48 billion kwhr (1933) to 55 billion (1934), the production of hydropower during the same period dropped from 32.5 billion to 30 billion kwhr.

The Perervinskaya HEP on the Moskva River was commissioned in 1935. The following plants were put into operation in 1936:

The Baksan HEP in the Northern Caucasus with a 10 km open diversion channel for power supply to the town of Nalchik and to the adjacent areas;

The Gizel'donskaya HEP, near the town of Ordzhonikidze, the first high-head plant in the USSR with a steel penstock 320 m long and three 8 Mw turbines for a head of 289 m;

The Kanakerskaya HEP, the first stage of the Sevan-Razdan power-plant cascade in Armenia; the plant was provided with an inclined tunnel (penstock) 4 km long and of cross section 5.6×5.3 m. Here, for the first time in Soviet practice, a plant was equipped with automatic wood-lined segment gates;

The Verkhne-Varzoboskaya HEP, the first plant in Tadzhikistan, with a diversion channel and a wood pressure tunnel 2 m in diameter; this was the first plant fitted with automatic butterfly gates of Soviet manufacture.

The most northern hydropower plant in the USSR was constructed near Murmansk in 1937 on the Tuloma River, which discharges into Kola Bay on the Barents Sea. A series of other plants were commissioned in the same year: the Gergebil'skaya Plant in Daghestan, with the highest arch gravity dam (69.5 m) in the USSR; the ATsGES (Adzharis-Tskhal'skaya HEP) in Georgia (with a pressure diversion tunnel, 2.9 km long and 4.4 m in diameter).

Effective harnessing of the great Russian river, the Volga, started during the second Five-Year Plan. In four years and eight months (1933 to 1937) the construction was completed of the huge complex of hydrotechnical structures, which is the Volga-Moskva canal im. Moscow (Figure 8), linking Moscow with the Baltic, White, and Caspian seas[24].

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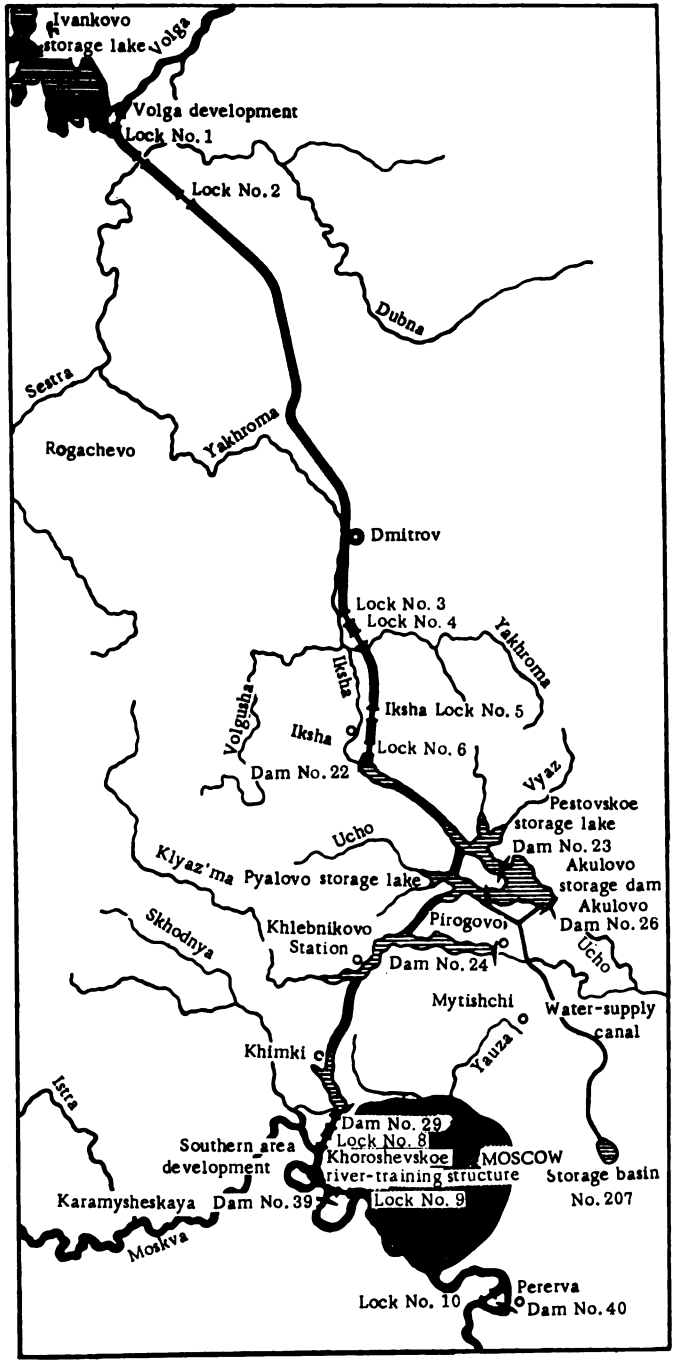

FIGURE 8. The route of the Volga-Moskva Canal

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The Volga-Moskva Canal is a remarkable hydrotechnical development. It is remarkable both for its length (128 km) and its technical features: it contains more than 240 different hydrotechnical structures, many of them of novel design. The canal has seven earth dams with heads of 14 to 27.5 m. The lengths of the dams added together come to 6.43 km. There are three concrete dams — one (the Ivankovo Dam) on the Volga River, and two on the Moskva River; 11 ship locks with 14 chambers with rated heads of 6.3 to 10 m; and eight hydroelectric plants — two of which, Ivankovo and Skhodna HEPs, with a total installed capacity of 60 Mw, were linked to the Moscow power network in 1937.

The head structure of the canal — Ivankovskaya HEP (Figure 9) — is located 120 km downstream from the town of Kalinin. The plant was commissioned in 1936, this marking the beginning of the comprehensive water-management of the Volga for power generation, water supply, and transportation.

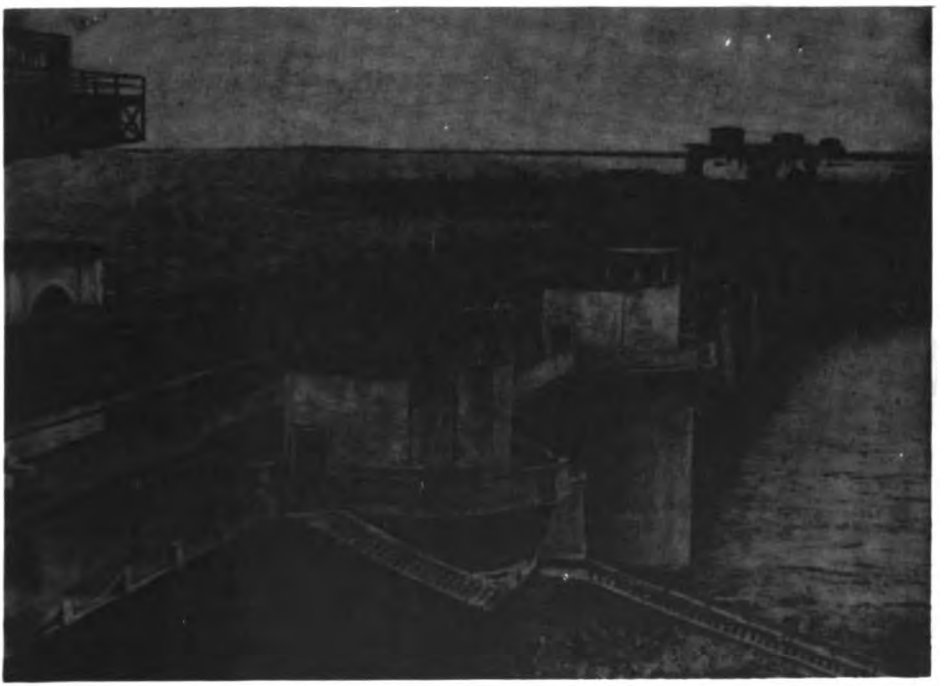

FIGURE 9. Tailwater view of the Ivankovskaya HEP

The concrete spillway dam (head 20 m) of Ivankovskaya HEP is the world's first hydrotechnical structure erected on morainic-clay ground (Figure 10). The relatively low spillway openings of the dam serve for runoff control in the headwater section of the plant and for floating-ice disposal. The sluiceways (bottom outlets) allow the discharge of flood-water and the disposal of floating debris and silt load.

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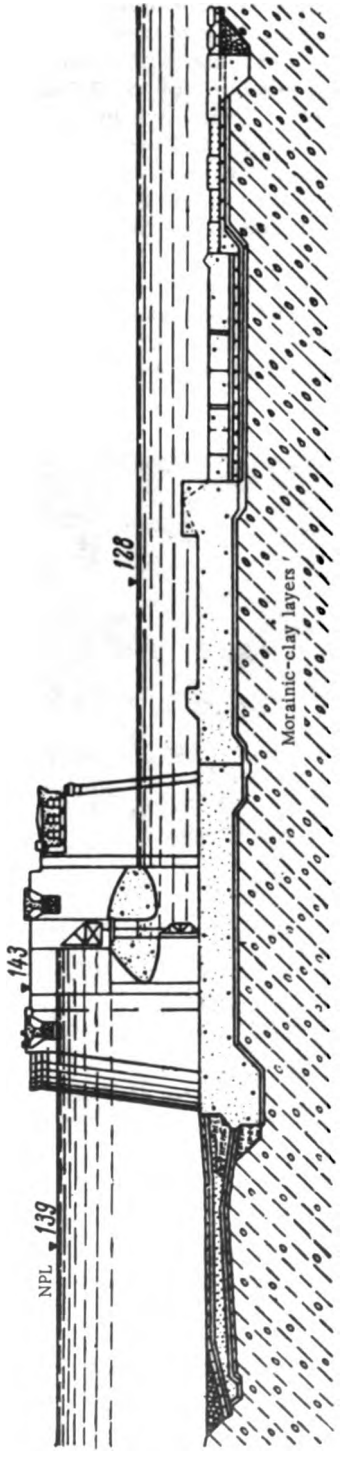

FIGURE 10. Spillway Dam of the Ivankovskaya HEP (section through the two-tier part of the dam)

The backwater created by the dam extends as far up the Volga River as the town of Kalinin. The volume of the storage reservoir, called the "Moscow Sea", is 1.2 billion m^3. The width of the reservoir is about 8 km; it has a surface area of 327 km^2. The storage lake is intended for runoff control of the Volga River and for the supply of water for the Volga-Moskva Canal.

Of particular interest is the hydraulic filling of the earth dam — the first large hydraulically filled hydrotechnical structure in the USSR. Filling was carried out with the aid of stationary suction dredges, equipped with slurry pipelines made of wood. The average daily output of the dredges was 3100 m^3, with the figure reaching 7920 m^3.

The Ivankovskaya station was the first Soviet HEP equipped with an outdoor power-house. The plant has two 15 Mw Francis turbines of turbine efficiency 93.7%. Turbine operation was made fully automatic. The Ivankovskaya HEP and several other Soviet plants now use remote-control methods.

The pumping stations of the canal are of great interest. Each of the five stations is equipped with centrifugal pumps capable of delivering 25 m^3/sec with a head of 8.5 m. The design of these huge pumps (impeller diameter — 2.5 m) is a remarkable Soviet achievement. The pumps are remote-controlled from a central control panel.

Another interesting and novel feature of the canal is the sector gates, used here for the first time in locks in the USSR, to replace the conventional two-leaf (plain sliding) gates. Many locks were also equipped with vertically sliding segment gates.

Twenty-two HEPs were constructed during the period of the second Five-Year Plan (total installed capacity about 540 Mw) and several existing plants were expanded. Thus, the Dnieper HEP im. Lenin, with an initial capacity of 310 Mw, was expanded to give 558 Mw.

The increase in energy output exceeded by a considerable degree the increase in installed power. This was mainly due to more efficient use of the installed capacity. The mean annual number of hours of power production increased from 1620, in 1932, to

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4180 hours in 1937. During the period of the second Five-Year Plan electricity output increased by more than five times, compared with the first plan, reaching almost 4.2 billion kwhr in 1937.

During the second plan, the total capacity of the plants increased by as much as 1.8 times, reaching, in 1937, 8235 Mw. Output increased to 36.1 billion kwhr against 2 billion kwhr in 1913 (i.e., an eighteenfold increase). During the same period in the U.S.A. the corresponding increase in output was only 6.7.

The annual increment in power output in the USSR during the period 1929 to 1937 reached 24.8%, exceeding the increment of all western countries (which had an average of 4.6% only). The per-capita consumption of electricity in the USSR reached 215 kwhr in 1937 against 14 kwhr in 1913 (a factor of 15.4). In the U.S.A., during the same period, the per-capita consumption only increased by a factor of 4.9. The USSR also ranks high as an efficient user of plant capacity [utilization], 61.4% in 1936, against 35.6% in the U.S.A., 28.8% in Great Britain, and 28% in Germany. These remarkable achievements of Soviet power engineering are due to the planned regulation of power consumption in the USSR.

The industrial use of electricity expanded greatly during the second Five-Year Plan. Prior to the revolution [1913], Russia occupied 15th place in energy production; during the period 1930 to 1935, the country was among the leaders, surpassing Great Britain, Canada, Japan, etc.

During the second plan still more stress was laid on the use of local fuel and on the expansion of water power. More than 80% of the power requirements of the country was met by power plants burning cheap fuel. During the same period the share of the total production of electricity generated at hydroelectric plants reached 11.5% (see Figure 71).

Despite the remarkable results achieved through the implementation of the five-year plans, the water-power resources of the USSR were far from being fully utilized at the time of the second plan. The USSR still lagged a long way behind the U.S.A. where, in 1937, hydropower accounted for about 33% of the total power generated.

However, further expansion in the field of hydropower was made possible as a result of the expansion in metallurgy and machine building, which took place during the five-year plans. The Leningrad Metal Works was the pace-maker in the manufacture of hydraulic turbines and equipment, frequently of higher quality than foreign products. In 1937 this factory manufactured the first Soviet turbine units to have automatic control. These were located on the Volga-Moskva Canal.

THE THIRD FIVE-YEAR PLAN (1938-1941)

The XVIII Congress of the CPSU, held in 1939, discussed and adopted the outlines of the third Five-Year Plan.

In the field of power generation, the plan established the following target figures: increase in energy output from 36.4 billion kwhr (1937) to 75 billion (1942). Growth of installed capacity from 8100 Mw (1937) to 17,200 Mw (1942). The higher rate of increase in installed capacity, compared with the increase in output, was aimed at creating a power reserve of 10 to 15%.

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The new plan also provided for further expansion in the utilization of waterpower. The production of hydropower in large, medium, and small hydropower plants was to increase by a factor of 2.3. Cascades of river plants were to become standard in hydropower generation.

The third plan envisaged the construction of the following large hydro-developments: two Kuibyshev plants totalling 3500 Mw; Kaluzhskaya HEP on the Oka River; Verkhne-Kamskaya HEP on the Kama; Mingechaurskaya HEP on the Kura; Ust-Kamenogorskaya HEP on the Irtysh; Gyumushskaya HEP on the Sevan-Razdan cascade; Uglichskaya and Rybinskaya HEPs on the Volga; Svirskaya No. 2 Plant; two plants on the Chirchik River in Uzbekistan, Kanakurskaya HEP in Armenia, the Khramskaya and Sukhumskaya plants in Georgia, as well as some smaller plants on the Ufa, Chusovaya, Belaya, Mias, Northern Donets, and some other rivers.

The XVIII Congress adopted a decision to improve river navigation, in particular, the reconstruction of river-navigation facilities on the Volga, Don, and Dnieper rivers, and the construction of the Volga-Don Canal[25].

The construction of the other two stages of the Volga cascade — the Rybinsk and Uglich plants — started in 1935. These two plants (of 330 Mw and 110 Mw, respectively), with their deep waterways, were intended to improve navigation between Moscow and the Volga, and to ensure a reliable power reserve for the Moscow power system. The installed capacity of these stages should have been 110 Mw for the Volga-Uglich project and 330 Mw for the Rybinsk project.

Today, a traveler going from Moscow to the town of Uglich on the Moscow Sea, can see a solitary church tower surrounded by water. Prior to the reconstruction of the Volga navigation facilities, this church stood in the town of Kalyazin. The town had to be relocated to make way for the huge storage reservoir. The Uglich storage lake starts downstream from Kalyazin. Its surface is 221 km^2. After a two-hour journey over the storage lake, we reach the Uglich hydro-development, which was commissioned in 1943. It comprizes two-tier concrete and earth dams with locks and powerhouse. A special spillway dam, 25 m high, forms the storage lake. This has a volume of 1 km^3.

The power plant is equipped with large (55 Mw) adjustable-blade turbines, runner diameter 9 m. These turbines were manufactured by the Leningrad Metal Works.

The third stage of the Volga-Rybinsk project was commissioned in November 1941. The plant has the same type of turbine units as the Uglichskaya HEP. The second turbine unit (Figures 12 and 66) was commissioned in 1942.

The hydraulic turbine for the Rybinskaya HEP was manufactured by the Soviet Elektrosila Plant and has the following characteristics: power 55 Mw; diameter of the water wheel 14.4 m; the load on thrust bearing during starting-up period reaches 2100 tons but is reduced to 1200 tons by means of special unloading electromagnets.

These new developments ensured a regular power supply to Moscow during the war, even during the heaviest months of battle. During the war Moscow received 3.5 billion kwhr. This allowed uninterrupted operation of its industry and saved more than 4 million tons of fuel.

Of particular interest is the Rybinsk hydro-development located at the junction of three rivers: Volga, Mologa, and Sheksna (Figure 11). The earth and concrete dams of the development are located on the Volga,

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upstream from Rybinsk; another earth dam and the powerhouse are on the Sheksna River. The dams on the Volga raise the water level by 16 m, creating a huge storage lake, the "Rybinsk Sea", which regulates the flow of the Volga (its discharge is 35.8 m^3) and permit constant power generation throughout the year. The area of the lake — 4600 km^2 — is almost equal in area to half the area of the Lake of Onega (see Figure 49). The storage lake, with a volume of 25.4 km^3, is quite impressive. The largest* storage lake in the world, Mead Lake in the U.S.A. (created by the Boulder Dam on the Colorado), has a volume of 43.7 km^3. During the navigation season the Rybinsk storage lake gives a discharge of 7 to 8 km^3 through the turbines. There is sufficient depth for navigation in the downstream stretches. The lake[26] has an average depth of 6 m, with the waves sometimes reaching a height of 2 to 3 m. There are eight special storm harbors.

The Rybinsk earth dam was filled with river sand. Although filling was carried out partly during difficult winter conditions, the strength of the dam is sufficient to resist the considerable pressure of the backwater.

A series of interesting reinforced-concrete designs were developed during the construction of various hydrotechnical structures: the idea of using flat welded girders as reinforcing elements in the construction of the Volga-Moskva Canal was subsequently adopted in the construction of the Upper-Volga hydrodevelopments, and later also in other Soviet projects. Soviet engineers developed a novel method of erecting reinforced-concrete structures, using facing shells instead of wood formwork[27]

At the construction site of the Uglich and Rybinsk developments, earth-moving amounted to 48 m^3 and was carried out mainly during the years 1936 through 1941, the top rate of 13.5 million m^3 being achieved during 1937. While the mechanization level of the construction work on the Volga-Moskva Canal was 45%, it reached almost 84% at these developments. On the construction site of the Volga project much equipment was employed: 72 excavators with bucket capacities of 1.5 to 2.5 m^3; 600 trucks; 23 large cranes; 113 locomotives; about 1000 railroad cars; 105 tractors; conveyors with a total length of 25 km; 22 main suction dredges; 40 auxiliary dredges; and 120 water giants [for excavation and hydraulic filling].

Almost 21% of all the earthwork (11 million m^3) was carried out using water giants and suction dredges. [Such operations are referred to in Soviet terminology as "hydromechanization" and this term has been retained in this translation.] The daily output of the hydromechanization equipment reached 36,000 m^3. For the first time, hydraulic filling of dams was carried out during winter, despite the subzero temperatures.

Ample railroad facilities greatly assisted in the site work, as they permitted quick removal of excavated material. Dump trucks were largely used in removing the excavated soil from the excavation pits. At the Rybinsk site, 1.7 million m^3 of soil were taken out in excavation that went down to a depth of 32 m. The material was removed in dump trucks.

Apart from the above-mentioned hydroelectric plants, completed during the prewar plans, the following plants and hydro developments were constructed: two stages of the Chirchik River cascade in Uzbekistan and the powerful stations, Komsomolsk near Tashkent (1940) and Tavak in Kazakhstan (see Figure 48). At these plants welded steel penstocks of 4.5 m diameter were used for the first time in the USSR.

* [At the time it was created.]

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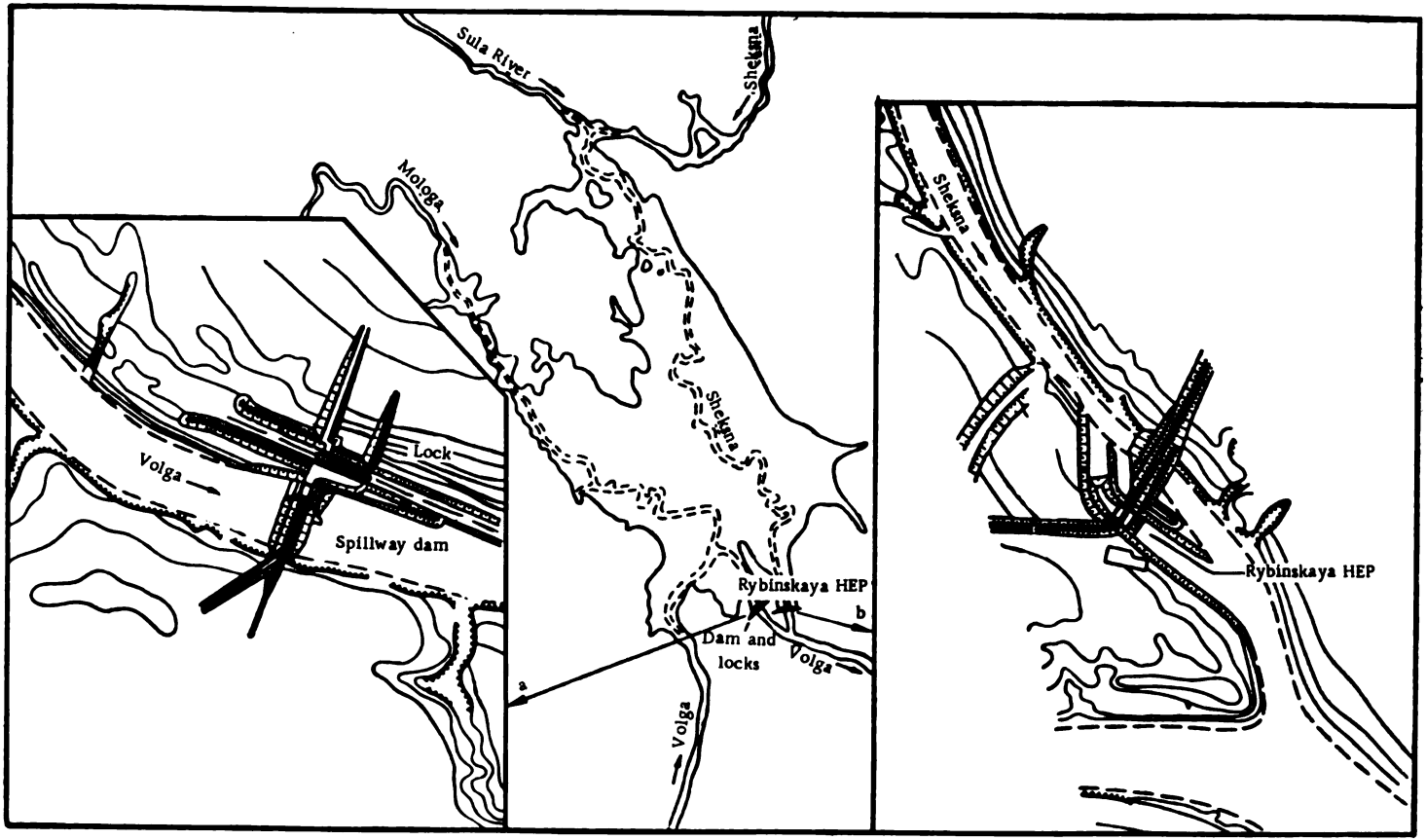

FIGURE 11. The Rybinsk hydro-development and the "Rybinsk Sea"

a —Volga site; b —Sheksna site

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The Kegums HEP in Latvia was expanded, receiving a third turbine unit. The last prewar plan also provided for power development in remote areas of the USSR, including, i.a., the construction of a third plant on the Niva River (Niva No. 3), in the far north. Site work was started for a second HEP on the Svir River and for a new plant on the Vuoksa (both in the Leningrad Area). In Armenia, after the completion of the Kanakerskii cascade (see above), construction of a water-intake structure and of the Ozernaya (underground) HEP started on the Lake of Sevan. Good progress was made on the Kuibyshev hydro development on the Volga, the Ust-Kamenogorskaya HEP on the Irtysh, the Mingechaur HEP on the Kura, the Verkhne-Kamskaya HEP on the Kama, etc.

The Second World War stopped construction work in the areas temporarily occupied by the Germans. The various structures had to be completed during the years 1941 and 1943. But the three years preceding the war (1938-1941) were marked by outstanding achievements in power generation. Installed capacity increased from 8235 Mw (1937) to 11,187 Mw (1940). In these total figures, hydropower accounted for 540 Mw. Output in the first three years of the last prewar plan increased from 36.2 billion kwhr (1937) to 48.3 billion kwhr (1940). These figures are a 250% improvement over the figures of the first year of the first plan. Compared with the rate for the year 1937, however, the rate of increase — 25.2% — was rather low: the plants commissioned at the beginning of 1940 did not operate all the year round.

During the period between 1928 and 1941, 39 large and medium hydroelectric plants were designed and erected. The share of hydropower in the power supply of the country thus increased from 4% to 10.4% and there was a steady trend to further increase[28] (Figure 71).

Another field in which rapid industrial expansion led to remarkable sucesses during the five-year plans was rural electrification (see Figure 19).

The deliberations of the XVIII Congress of the CPSU had a strong impact on the further development of hydro construction: thus, in a single day on 12 March, 1939, more than 30,000 kolkhozniks participated voluntarily in the construction of the Lyagan Canal, which links the Isfara and Shakhimardan rivers. The same work methods were used in the construction of the Great Fergana Canal (271 km) for the diversion of the Naryn River into the low runoff Kara Darya River.

Much effort was directed to the introduction of automation and remote control into power generation. Thus, in 1940, five HEPs on the Volga-Moskva Canal were switched over to automation and remote control. The experience gained at these stations served as a guide in further work on the automation of power plants (see Figure 18).

During the last prewar plan period the construction of high-tension transmission lines continued at an ever-increasing rate (see Figure 30). In 1940, the length of 11 kv lines reached 22,500 km, including about 14,000 km of 110 kv lines. Further progress was also achieved in the interconnection of power systems. On the eve of the war, the most important of the regional power systems — the Moscow, Leningrad, Gorki, Ural, Donets, and Dnieper systems — supplied almost 2/3rds of the total energy produced in the USSR.

Such a rapid expansion of power generation was inconceivable without a suitable machine-building industry. Whereas in 1930, of the total number of turbines and generators installed, Soviet-made turbines and generators

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represented only 10.7% and 11.6%, respectively, of the total in 1938, the share of Soviet-made equipment reached 80.4% for turbines and nearly 100% for generators. In 1940, the USSR completely stopped the import of foreign power equipment.

THE WAR PERIOD (1941-1945)

During the war power construction and generation in the USSR sharply dropped. Of the 5 million kw of installed capacity destroyed during the war (almost half the installed capacity of the USSR in 1940), one million kw were contained in hydroelectric plants. Eleven power stations were destroyed or heavily damaged, among them were the Dnieper, Nizhne-Svirskaya, Kegums on the Western Dvina, Kondopozhskaya on the Suna, Niva No.2 HEP in the Kola Peninsula, and the Baksanskaya and Gizel'don-skaya plants in Northern Caucasus. The No.1 Volkhov HEP was temporarily closed down due to heavy damage. Some hydro structures on the White Sea-Baltic Sea canals, and the navigation network linking the Svir, Western Dvina, Neman, and some other rivers suffered heavy damage. Many dams and storage lakes in Donbass and the Ukraine were destroyed.

The most severe damage was inflicted on the Dnieper HEP. In a report of the Soviet reconstruction crew which arrived at the town of Zaporozh'e on 11 March, 1944, the following damage is described: complete destruction of the baffle wall in front of the powerhouse and destruction of the concrete dam and powerhouse. As a result of the lowering of the headwater level of the plant, the rapids on the Dnieper River, formerly (1932) covered by the headwater, were exposed. The power and auxiliary equipment was also heavily damaged.

Despite the heavy burden the war laid on the Soviet people and industry, every effort was made not to weaken the construction program of power plants in the eastern regions of the country, to which part of the Soviet industry had been temporarily transferred from the western areas.

As early as August 1941 the Soviet government and the Central Committee of the CPSU adopted a decision calling for the urgent construction and rapid commissioning of new power-generating capacity in the Transvolga and Ural regions, Western Siberia, Kazakhstan, and Uzbekistan. This decision provided for the installation, in the last quarter of 1941, of 298 Mw and 1088 Mw in 1942[29].

During three years of the war (1942-1944), 3400 Mw of installed capacity were put into operation, while the capacity of the existing plants was greatly expanded. During the war more than 40 new plants were commissioned in Soviet Central Asia, the Ural Area, Transcaucasia, etc. A series of power plants were completed in an unprecedented short time — one to one and a half years — due to the sustained efforts of the Soviet people. The method of voluntary work, adopted first in the construction of the Great Fergana Canal, ultimately became a general method of construction (see Figure 48). Thus, on the construction site of Uzbekistan is the largest hydropower plant — the Farkhad HEP on the Syr Darya River— 65,000 kolkhozniks excavated 2 million m^3 of rock and earth for the hydro-technical structures[30].

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The Farkhad hydro development serves a dual purpose: irrigation and power generation. The earth dam, made of loess, created a storage lake with a volume of 620 million m^3. The welded-steel penstock has a diameter of 6.5 m; the diversion channel has a record length of 22 km.

A satisfactory volume of work was carried out in Uzbekistan on the construction of the Bozsu irrigation project: construction of Nizhne-Bozsuiskaya No. 1 and 2 Power Plants, completion of Aktepinskaya HEP, Akkavakskaya Plants Nos. 1, 2, and 3, Salarskaya HEP, Sharikhanskie Nos. 6 and 7 plants, and the expansion of the Tavakskaya HEP. Some of these plants were equipped with turbines transferred from the western regions of the USSR on the eve of war.

Despite the low degree of mechanization, the duration of construction was extremely short. Thus, Akkavakskaya No. 1 HEP (11 Mw), started in 1947, was completed in only 17 months; Salarskaya HEP (11 Mw) was completed in 13 months. The construction of Nizhne-Bozsuiskaya HEP, including earthwork amounting to 500,000 m^3, was completed in 21 months.

Power construction greatly expanded also in Kazakhstan. A chain of medium power plants was constructed on the Almatinka River to ensure the power supply to Alma-Ata, the capital of the republic. Work continued also on the construction of the large plant on the Irtysh — the Ust-Kamenogorskaya HEP.

Two power plants were put into operation in 1945: the Alamedinsk No. 1 HEP near the town of Frunze, and the Taligulyanskaya HEP near the town of Samarkand. Construction work started on the second Tadzhik Plant — Nizhne-Varzobskaya HEP.

Power construction also continued steadily in the Caucasus and Transcaucasian regions. Ozernaya, Khramskaya, and many other HEPs were commissioned in Armenia and Georgia. Work continued on the reconstruction of plants damaged or destroyed during the war in Northern Caucasus. Site work began on several medium plants: Krasnopolyanskaya, Maikopskaya, and Ordzhonikidzevskaya HEPs.

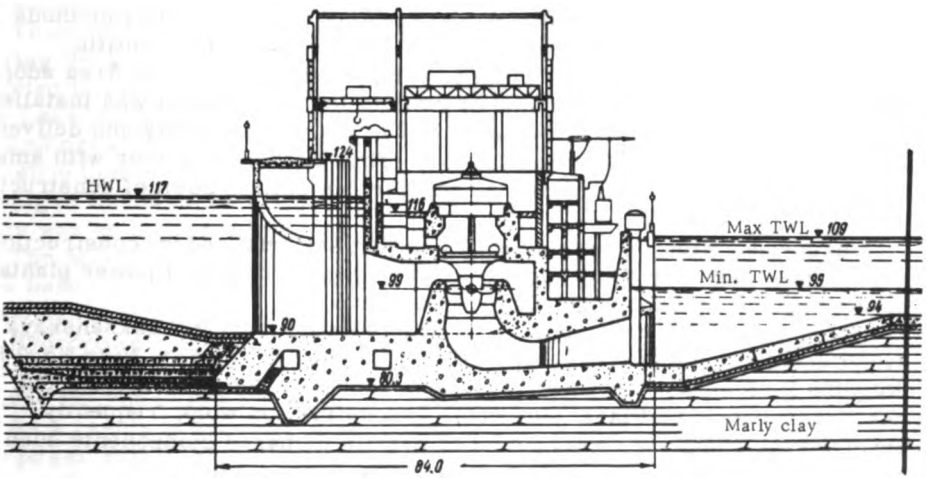

FIGURE 12. Section through the Rybinskaya HEP

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At the same time, construction continued on the following projects: Alpaevskaya, Verkhoturskaya, and Argazinskaya HEPs in the Ural Area, Enso HEP on the Vuoksa River, and some other plants in the northern and central regions of the country.

The largest plant commissioned during the war was the Rybinskaya HEP (Figure 12), the third stage of the Volga cascade. The plant is located at the diversion channel on the right bank of the Sheksna River (see Figure 11); the powerhouse of this station is 216 m long; it is provided with an anchor apron. The adjustable-blade turbines of the six 55 Mw units have runners of 9 m diameter. The first turbine unit of the plant was put into operation in November 1941[31].

During 1943, the total output of Soviet hydroelectric plants increased by 9.4% compared with the preceding year; the 1944 increase, compared with 1943, was 30%.

War-time conditions had a considerable effect on the thinking of designers and engineers, who strove to reduce to a minimum the use of scarce materials, skilled labor, and complicated equipment. Thus, earth dams of the so-called Uzbek type were built: the dam was constructed by hydraulic filling, without any additional compaction of the fill. This method was used in the constructions of the dams of the Nizhne-Bozsuiskaya HEP, and the Salarsk HEP. The dam for the Farkhadskaya HEP was constructed by throwing the stone for the dam body directly into the running water. The baffle walls of the powerhouse were made as earthfill walls. Some dams were constructed by blasting river-bank rock and dumping the debris in the water.

The diversion channels of the Chirchik HEP (discharge 300 m^3/sec) were constructed despite difficult geological conditions (gravel, loess, and other heavy soils).

Great advances were made during the war in theoretical hydraulics. Thus, a new method was developed for calculating nonsteady flow in open channels; new aspects of the theory of uplift pressure were developed and a new approach was worked out for gravity seepage below foundations in coarse-grained materials, rockfill, and nonhomogeneous soils.

War-time conditions greatly encouraged the development of methods aimed at speeding up construction work. After thorough scientific investigation, the builders of hydropower projects in the Ural Area adopted the so-called "combined" method of installation: equipment was installed in large combined blocks, preassembled in the assembly bay and delivered to the work area ready for installation. This method, together with small-scale mechanization, permitted a considerable cutting down of construction time.

Concurrent with the expansion of existing stations, and the construction of new plants, work advanced quickly on the reconstruction of power plants in the regions reconquered from the Germans.

Thus, in a short time, special teams reconstructed the Baksanskaya and Gizel'donskaya plants (1944), Nizhne-Svirskaya HEP (1945), Niva No.2 HEP, Kegums HEP on the Western Dvina, the Raukhiala Plant on the Vuoksa, the Kondopozhskaya Plant, etc. This reconstruction work frequently involved the complete replacement of heavily damaged components such as turbine shafts, runners, distributors (guide vanes), etc.

The Nizhne-Svirskaya HEP was rebuilt to its previous size without any essential changes in layout and without lowering the headwater level. The

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first rebuilt turbine unit was put into operation in 1945. Reconstruction of the plant was completed in 1948[32].

The volume of work involved in the reconstruction of the Dnieper HEP was larger than that needed for its initial construction (1927-1932); now involved was the demolition of 200,000 m^3 of reinforced concrete and more than 20,000 tons of steel structures and heavily damaged equipment, which had to be replaced with new structures and equipment. Reconstruction started in March 1944, and was largely completed immediately after the war. More than 5000 workers were engaged in the work.

In the course of reconstruction, some changes were introduced into the layout. The height of the Stoney gates was increased, thus increasing the useful head by 1 m. Of the 45 piers of the dam, 32 had to be completely reconstructed. The powerhouse had been entirely destroyed and was completely rebuilt. To speed up commissioning of the plant, the Soviet Government imported three turbines from the American company, Newport News, the same company that had furnished the first power equipment for the first Dnieper HEP. The other turbines were supplied by Soviet manufacturers.

Three years after the beginning of the reconstruction of the Dnieper HEP on 3 March, 1947, the first turbine was ready for operation. The completely reconstructed HEP was to have an installed capacity of 648 Mw, i.e., 16% more than its prewar capacity.

Six other hydropower plants, with a total capacity of 260 Mw, were reconstructed toward the end of the war.

The sustained efforts in the construction of new power-generating capacity in the eastern and central regions of the country, had a big influence on industry in these areas. The use of local fuel made it possible to cope with the increased demand for power. Also, regions whose power supply comes from hydroelectric plants, were now able to receive uninterrupted supply from various hydroelectric plants (e.g., stations in the Murmansk area, Armenia, Georgia, etc.).

Hydroelectric plants, being independent of fuel supply, played an outstanding part in sustaining the war effort of the USSR.

Thus, the Volkhovskaya HEP im. Lenin operated without interruption during the blockade of Leningrad. At the beginning of 1942, the plant started to operate again and a 122 km transmission cable was laid across the Lake of Ladoga in only 45 days, thus ensuring continuous power supply to Leningrad's industry. The laying of such a long cable required the construction of a floating bridge that carried the full length of cable. The laying of the cable on the bottom of the lake was carried out in only 75 hours. This was an unprecedented achievement[33].

The Murmansk power industry was also cut off during the war from its fuel base. Great use was made of hydropower and this was of particular importance in the continuous operation of Murmansk harbor.

Hydropower plants in the nonoccupied territories of the USSR during the war saved more than 17 million tons of coal and other fuel, freeing 15,000 railroad cars for other, more urgent, tasks.

As a result of the shift of the power industry to the eastern regions, the power supply of the country underwent considerable changes (see Table 12).

The increase in the share of the power industry in the Ural Area, Siberia, and the Soviet Central-Asian region in 1945 was due not only to the

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relocation of the power industry from the Western regions, but also to the construction of new power plants in the eastern regions.

TABLE 12
The share of the East and Soviet Central Asia in the total power supply of the USSR

Region	Power generation, %	
	1940	1945
Ural Area	12.8	28.3
Siberia and Far East	6.6	14.2
Soviet Central Asia	2.8	6.0

Expansion of power generation in the eastern regions, the construction of new power plants with a total of 5 million kw of installed capacity, and the quick reconstruction of power plants destroyed during the war, helped to replace the enormous losses of installed capacity due to the war.

Shortly after the war (1945), the installed capacity of Soviet hydropower plants was brought close to the prewar level (1940). However, the installed capacity of these plants still lagged behind. In 1945 their total power was 1300 Mw, against 1600 Mw in 1940. Output in 1945 was 4.8 billion kwhr against 5.1 billion kwhr in 1940. Thanks to sustained efforts, this discrepancy was quickly canceled; by 1946 prewar levels of both installed capacity and output were surpassed (see Figure 73).

THE FOURTH FIVE-YEAR PLAN (1946-1950)

The fourth Five-Year Plan, adopted by the Supreme Soviet of the USSR on 18 March, 1946, provided for "the quick reconstruction of the regions that suffered during the war, to restore the prewar level of industry and agriculture, and to exceed this level"[34].

In the new post-war plan, particular attention is given to the further development of power generation and utilization. Thus, the installed capacity of power plants was to increase, by 1950, to 22.4 million kw (up to 5 million kw of which was to be hydropower). While the GOELRO plan envisaged the construction, within 15 years, of ten HEPs with a total power of 640 Mw, the fourth plan provided for the construction of new medium and large plants, with a total installed capacity of 2300 Mw, and new small plants with a total capacity of 1000 Mw for rural electrification.

The annual power output was to reach 82 billion kwhr by 1950, i.e., to increase by 70% compared with 1940. The share of hydropower in the total power production was to increase to 15.2%.

The fourth plan provided for the reconstruction of six plants destroyed during the war, including the Dnieper Plant; the completion of 30 other plants; and the start of construction on 13 other plants. In the course of this reconstruction program, the first turbine unit of the Dnieper HEP was commissioned on 3 March, 1947; five other units were recommissioned

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in 1949, and the tenth and last unit on 30 June, 1950. The completely rebuilt plant was equipped with new more powerful turbines (unit capacity up to 72 Mw), with excellent characteristics — even better than those of the American turbines installed in the prewar plant.

By increasing the efficiency of the turbines, it became possible to increase the power output of the plant. The present-day installed capacity (648 Mw) is equivalent to the power of ten Volkhov plants. The annual output (about 3.9 billion kwhr) exceeds the annual output of all Tsarist plants together. During its 30 years of operation, the Dnieper HEP has produced 56 billion kwhr — more than Tsarist Ukraine could have produced in 112 years!

The Dnieper HEP is connected to the Dnieper and Donbass power systems. The power supply from the HEP is carried over a network of 220, 154 and 35 kv lines, which embraces the largest industrial centers of the Dnieper area: Dnepropetrovsk, Zaporozhe, Dneprodzerzhinsk, Krivoi Rog,[35] etc.

During the period of the fourth plan, tens of new plants were commissioned, among these were, Verkhne-Svirskaya, Tsimlyanskaya, Nivskaya No. 3, Narvskaya on the Narova River, Enso on the Vuoksa, Dubossarskaya on the Dniester River, Farkhadskaya on the Syr Darya, Khramskaya No. 1 and Sukhumskaya in Georgia, Ozernaya — the highest plant of the Sevan-Razdan cascade, Gyumushskaya — the largest of the same cascade, Krasnopolyanskaya on the Mzymta River near the town of Sochi, Maikopskaya on the Belaya River, Pavlovskaya Plant on the Ufa, Svistukhinskaya in the town of Stavropol, Shirokovskaya on the Kosva River in the Ural Area, etc.

The construction of the following plants was started during the same period: Gorkovskaya Plant — the fourth stage of the Volga cascade, Permskaya Plant near the town of Perm, Ust'-Kamenogorskaya Plant on the Irtysh, Novosibirskaya Plant on the Ob' River, and many others.

More than 40 plants with a total installed capacity of 2300 Mw were commissioned, and 55 plants were in the construction stage. Some of the latter were completed during the next (fifth) Five-Year Plan.

The Khramskaya HEP, commissioned during the fourth plan, is the station with the highest head in the USSR. The plant, erected on the Khrami River at an altitude of 1500 m above sea level, has a 430 m high dam that creates a storage lake with an area of 35 km^2 and a volume of 200 million m^3. The dam is of rockfill type and has a steel sheet piling for seepage prevention. The 8 km pressure tunnel is the longest in the USSR. The tunnel is connected to the steel penstock, which has a diameter of 1.45 to 3.0 m. The plant has three Pelton turbines each of 30 Mw. The storage lake ensures runoff and discharge regulation for the whole cascade.

The construction of the Khramskaya HEP was not an easy undertaking. A special 230 km access road had to be built through the mountains. The water tunnel had to be gunited and special steps had to be taken to prevent seepage from the storage lake.

The Gyumushskaya HEP is the third plant of the Sevan-Razdan cascade. It has a head of 290 m. The maximum discharge of the Razdan River is 280 m^3/sec. The dam is of the rockfill type with steel-sheet piling. It has a height of 30.5 m and a length of 105 m. The gravity-flow (inclined) diversion tunnel has a length of 12 km and is connected to an open channel 7 km long. The daily excavation rate of the tunnel, which has a cross section of 22 m^2, reached 7 m. In the construction of this tunnel, a

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technique suggested by K. N. Romanovich, the so-called "extrusion excavation" was used for the first time. The concrete lining of the tunnel was carried out by the "moving shield" technique, developed by V. A. Slovinskii. The plant has Francis turbines built by the Leningrad Metal Works for the highest head ever used in the USSR. The following figures give some idea of the construction work involved in setting up this plant: 390,000 m^3 of ground excavated, 413,000 m^3 of concrete placed, and 7500 tons of steel structures erected.

The construction of the Nivskaya No. 3 HEP on the Kola Peninsula near the town of Kandalaksha, started in 1934, and was completed in 1949. This plant has many novel features which distinguish it from other hydropower plants in the USSR (Figure 13). To ensure proper protection of the equipment from ice, the powerhouse was built underground at a depth of 60 m. The diversion channel has a total length of 7.6 km. The dam was erected at a point 13 km upstream from the river mouth. The lengths of the penstock and outlet channel are 2.6 km and 2.8 km, respectively. Both structures have the same diameter of 12 m. The size of the excavation required by the powerhouse (13.5 × 76 × 27 m) makes this powerhouse one of the largest underground powerhouses in the world[36].

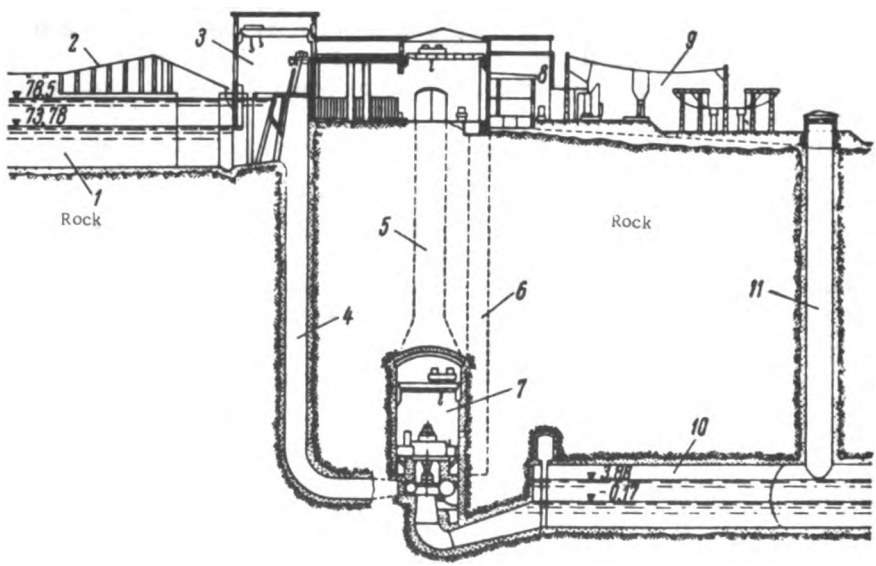

FIGURE 13. The Nivskaya No. 3 HEP on the Kola Peninsula, with underground powerhouse

1 — diversion power channel; 2 — covering of the channel; 3 — screen (gate) house; 4 — 4.5 m diameter penstock; 5 — assembly shaft; 6 — busbar gallery; 7 — underground powerhouse; 8 — control board; 9 — transformer station; 10 — outlet tunnel; 11 — air shaft

The following figures illustrate, better than any text, the enormous amount of work carried out in Soviet power construction during the fourth Five-Year Plan.

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TABLE 13

Basic power-construction work

Plan	Type of work			
	earthmoving excavation, million, m^3	earthfill, million, m^3	plain and reinforced concrete, thousand m^3	length of tunnels, km
1936 — 1940	22	2.6	860	40
1941 — 1945	17	2.9	520	
1946 — 1950	60	34.0	4600	30

Until 1948, the degree of mechanization in power construction was still unsatisfactory (Table 14). From 1948, this position improved considerably: 84% of all earthwork (8.5 million m^3 was carried out by mechanical means, including 2 million m^3 by hydromechanization. In 1947, 285,000 m^3 were handled by hydromechanization.

TABLE 14

Mechanization of earthmoving and excavation work in power construction

Year	Work done by mechanical means	
	million m^3	% of total work
1940	0.75	33.5
1946	1.50	40.0
1947	2.80	40.0
1948	8.50	84.0

Toward the beginning of the fifth plan (1951), the postwar reconstruction period was virtually completed. By this time, the Soviet Union had achieved outstanding results in power generation and utilization. Output in 1950 was 91.2 billion kwhr, exceeding the 1940 level by 87% (the target figure was only 70%). The installed capacity of power plants reached 19.6 million kw, exceeding the prewar level almost 1.75 times. The yearly increment in installed capacity exceeded, by a factor of almost 2, the figures outlined in the GOELRO Plan for a 10 to 15 year period.

Within the framework of the post-war reconstruction plan, the installed capacity of hydroelectric plants increased by nearly 2 million kw (157%), and, in 1950, reached 3.2 million kw (16.4% of the total capacity of Soviet power plants).

The power output of hydropower plants increased by 7.9 billion kwhr (250%), reaching 12.7 billion kwhr in 1950 — a yearly increment of more than 21%. The share of hydropower in the total power supply reached 15.2% in 1950 (against 10.5% in 1940). Compared with 1932, the output of hydroelectric plants had increased by 1580% (i.e., more than 15 times); compared with 1913, more than 45 times. In terms of output, in 1950 the USSR occupied the first place in Europe. In the world the USSR was exceeded only by the U.S.A. in this context.

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AUTOMATION OF HYDRO PLANTS

The fourth plan devoted much attention to the introduction of automatic control into hydroelectric power plants[37].

Automation increases the reliability of plant operation, reduces breakdown, gives quick start-up and shutdown to meet load fluctuations, and markedly reduces the need for servicing and maintenance personnel. Automated hydropower plants are switched on by pressing a push button on a control panel located sometimes several hundreds of kilometers from the plant. Oil supply to the bearing, opening the gate valves for water supply to the turbine units, and the operation of the generators, are all controlled automatically. In case of emergency, automatic equipment ensures quick stoppage and signaling to the control panel.

Work on the automation of hydropower plants was carried out on a large scale during the fourth plan. In 1940 only 0.2% of hydropower plants were automated; in 1950 almost 71% of regional plants were automated (see Figure 18).

In 1946 the Burdzharskaya HEP in Uzbekistan was completely automated. By 1948 all the hydroelectric plants in this republic had been fully automated, and by 1949 all the plants of the Moscow system were also completely automated.

The Dnieper HEP, built in 1932, and equipped with up-to-date gear, had a service staff of 230. After the war, the plant was fully reconstructed and provided with automatic equipment that reduced servicing personnel to six shift operators.

Remote control is also important in the automation of HEPs, since it permits the control of several plants from a single load-dispatching center. Thus, in 1944, remote control was introduced at the Ivan'kovskaya HEP, linked to a control center located 70 km from the plant. The Uglichskaya and Rybinskaya HEPs are controlled from a central point at a distance of 200 km from the plants.

In 1940 only 0.2% of regional plants were provided with remote control; by 1950 this figure had increased to 22.2% (an increase of more than ten times).

The last year of the fourth (postwar) plan was a year of remarkable successes [sic]: in August-September 1950 the Soviet Government decided to construct the following large hydrotechnical structures: two plants on the Volga, Kakhovskaya Plant on the Dnieper; and the Main Turkmenia Canal, with a series of power plants located along its route. In December of the same year the Government decided to speed up the construction of the Volga-Don navigational canal and the associated Tsimlyanskaya HEP, and the construction of an irrigation system for the Rostov and Volgograd districts.

THE FIFTH FIVE-YEAR PLAN (1951-1955)

The directives of the XIX Congress of the CPSU for the fifth Five-Year Plan laid still greater stress on the development of power construction. According to the new plan, overall industrial production was to increase

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by 70%, and power generation by 80%. The new plan envisaged the commissioning of a series of large power plants: Kuibyshevskaya HEP, the Kamskaya, Gorkovskaya, Mingechaurskaya, and Ust-Kamenogorskaya plants, etc., with a total installed capacity of 3916 Mw. The directives also provided for the construction of new hydroelectric plants: the Volgogradskaya and Cheboksarskaya plants on the Volga, Votkinskaya HEP on the Kama, the Kakhovskaya plant on the Irtysh, the Irkutskaya and Bratskaya plants on the Angara, etc.

During the period from 1951 to 1955, Soviet power engineering achieved unprecedented successes, both in installing new capacity and in increasing output (see Table 15). From 1950 to 1955 the installed capacity increased from 19.6 million kw to 37.2 million kw. Output during this period increased by 86.8% (target figure only 80%), reaching 170.2 billion kwhr.

TABLE 15

Construction of power plants and generated output during the Five-Year Plans

Characteristics	Annual growth					
	1st F.Y.P.	2nd F.Y.P.	3rd F.Y.P. 3 year period	4th F.Y.P.	5th F.Y.P.	1955
Installed capacity, Mw	692.9	711.6	986.0	1698.0	3524.4	4431
As % of the preceding Five-Year Plan	—	101.2	140.1	172.3	207.8	—
Output, million kwhr	2100	4500	4000	9600	15,800	19,530
As % of the preceding plan	—	214.3	87.7	240.0	164.8	—

By the end of this plan period, the Soviet Union had consolidated its first place in Europe and second in the world, generating, in 1955, as much power as was produced by Great Britain and the West German Federal Republic.

During this plan period, apart from the tremendous development of power generation and utilization, remarkable successes were achieved in the field of hydropower. Hydroelectric generation increased by about 10.5 billion kwhr (i.e., by 82%), and reached 23.2 billion kwhr (1955). Installed hydroelectric capacity increased by 86%, reaching 6 million kw. During the period of one Five-Year Plan installed capacity increased by 2768 Mw, or twice the capacity increase achieved during all the prewar Five-Year Plans together.

Despite these outstanding hydropower figures, the major part of power generation was still done at thermal power plants: in 1955, the share of hydroelectric plants was only 16.6%, while the capacity of thermal-power plants reached 4/5ths of the total generator capacity.

The period of the fifth plan was a time of tremendous progress in hydropower construction. During this period 24 hydroelectric plants, with a total installed capacity of more than 5 million kw, were constructed in various regions of the USSR. Almost half of this capacity was commissioned by the end of 1955. During this period the total generating capacity of the hydropower plants in the Ural and eastern regions increased

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at a greater rate than in other regions. This was due to the fact that the best geographical distribution of new power plants was being sought.

A particular feature of power construction peculiar to the postwar period was the creation of power-plant cascades on various rivers. Such cascades are an extremely efficient way of achieving river control and runoff regulation, and are thus of extreme importance to the whole national economy.

TABLE 15A

Hydroelectric plants brought to full operation 1951-1955 [36]

Name of power plant	Located on river	Republic or region	Commissioned
Nizhne-Varzobskaya	Lower Varzob	Tadzhikistan	1951
Akkavakskaya (1st stage)	Bozsu	Uzbekistan	1951
Nizhne-Bozsuiskaya No. 2		"	1951
Verkhne-Svirskaya	Svir'		Feb. 1952
Tsimlyanskaya	Don		Apr. 1952
Nizhne-Varzobskaya No. 2	Lower Varzob		Nov. 1952
Niva No. 1		Murmansk	Dec. 1952
Matkozhnenskaya	Karelia		Jan. 1953
Gyumushskaya		Armenia	Apr. 1953
Sheikhantaurskaya	Bozsu	Uzbekistan	June 1953
Ust'-Kamenogorskaya	Irtysh	Kazakhstan	July 1953
Ozemaya (Alma-Ata cascade)			Oct. 1953
Kegums	Western Dvina	Latvia	1953
Shaarikhanskaya No. 7	Kara-Daria	Uzbekistan	Dec. 1953
Mingechaurskaya (357 Mw)		Azerbaidzhan	1954
Nizhne-Bozsuiskaya No. 6		Azerbaidzhan	Aug. 1954
Pal'eozerskaya	Suna	Karelia	Nov. 1954
Ezminskaya	Terek	Caucasus	Nov. 1954
Alma-Atinskaya No. 8 (Alma-Ata cascade)		Kazakhstan	Nov. 1954
Ortochal'skaya	Kura	Georgia	Dec. 1954
Dubossarskaya	Dniester	Moldavia	Dec. 1954
Svistukhinskaya and Sengileevskaya No. 1	Nevinnomysskii Canal	Stavropol'	1954
Nizhne-Bozsuiskaya	Bozsu	Uzbekistan	1955
Sharoskaya	Dudi-Chala	Georgia	1955
Belorechenskaya	Belaya	Krasnodar	1955
Narova	Narova	Estonia	Dec. 1955

During the years 1954 to 1955 the first units were put into operation at the following hydro plants: Perm', September 1954, 126 Mw; Knyazhegubskaya on the Kova River in Karelia, October 1955; Gorkovskaya on the Volga, November 1955; Kakhovskaya (the downstream stage of the Dnieper power cascade, October 1955; Volga im. Lenin, one of the largest hydroelectric plants in the world, December 1955.

Much effort was spent during the period 1951-1955 to speed up hydropower construction. The Tsimlyanskaya HEP was built and the first units put into operation in less than four years. The cornerstone of Ust-Kamenogorskaya HEP powerhouse was laid in July 1951; 16 months later the plant was supplying current. The Kakhovskaya HEP was constructed and commissioned in less than five years, much ahead of schedule.

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The construction of the Volga-Don Canal, which started several years after the war, was rapidly approaching completion: on 31 May, 1952 the waters of the Volga mingled with the waters of the Don, and on 22 July of the same year, the canal was ready for navigation. Its aim was to connect all the seas of European USSR to form a single waterway[39], and to make Moscow a port with access to the five seas.

Figure 14 shows that the Volga-Don Project im. Lenin comprises a navigation canal of 101 km (including 45 km of artificial storage reservoirs), with 13 locks (including ten locks on the Volga, subjected to heads of 10 to 13 m); and Tsimlyanskaya HEP, on the Don River, with an installed capacity of 160 Mw and an output of 46 million kwhr per year.

Tsimlyanskaya HEP has a concrete spillway dam with a fish lock, and a powerhouse built into the dam. This latter has a length of 600 m, and contains a volume of 1200 million m^3 of reinforced concrete. Adjacent to the concrete dam is an earth dam with a length of 12.75 km (the total length of the water-retaining structures is 13.35 km). More than 29 million m^3 of a total of 32 million m^3 of the dam were handled by the hydraulic-fill method, using local sand from the adjacent flood-plain deposits. About 3 million m^3 of clay were also used in the hydraulic fill.

The dam raised the level of the Don River by 26 m, creating an impressive storage reservoir 40 km wide and 350 km long, with an area of 2700 km^2 and a useful capacity of 12.6 billion m^3 of water (total volume 23.8 billion m^3). The dam permits long-time runoff regulation of the Don River, and more efficient utilization of the capacity of the HEP.

The water of this lake would fill a canal 30 m wide, 5 m deep, and more than 15,000 km long. Special storm harbors on the lake provide safe anchorage for ships during storms.

The powerhouse has four turbine units each of 41.5 Mw. For the first time, the step-thrust bearing of a turbine unit, usually installed below the generator, was brought out and located on the generator cover, thus saving, on each unit, up to 120 tons of metal and 120 tons of concrete. The length of the shaft was reduced by 3 m and the height of the powerhouse by a corresponding amount (see Figure 66).

The Tsimlyanskaya HEP supplies sufficient power for trouble-free operation of the various elements of the canal.

Of particular importance in the comprehensive utilization of the Volga-Don complex is the irrigation of large areas of arid land (2,750,000 ha) in the river basin. The interests of the fishing industry were not neglected in planning this huge project. As mentioned, the canal is provided with a special fish ladder and many fish-processing plants have been erected along its shores.

The fish lift (Figure 15) is intended for the passage of valuable fish from the tailrace of the dam upstream to the storage lake. It consists of a reinforced-concrete supply flume in the tailrace (downstream piers) and a fish lock with horizontal measurements of 6.2 × 5.0 m. The lift raises the fish vertically from the tailrace to the headrace. Fish also pass down the river to spawn. These are directed to the upper piers of the fish passage. Large fish cannot enter the suction pipes of the turbines, being prevented from doing so by a steel screen, that stretches from the head of the upper piers to the bank at an angle of 45°. Moving along the screen, the fish reach the inlet of the flume situated at the downstream pier. In this stretch of the flume a small turbine creates a stream of water for the fish lift.

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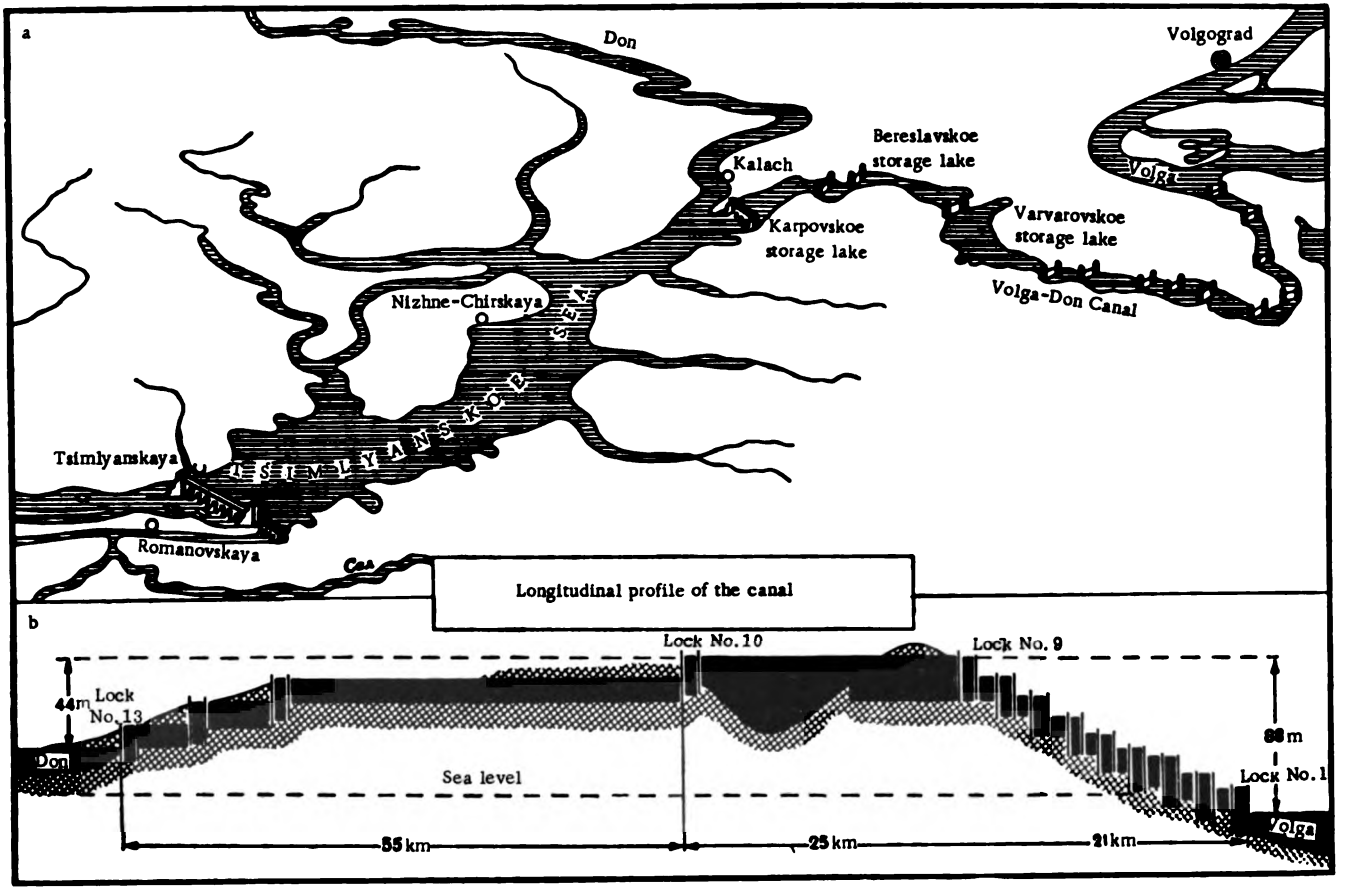

FIGURE 14. The Volga-Don Navigational Canal im. Lenin

a — plan; b — longitudinal section

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Moving through the flume, the fish reach the shaft of the vertical lock in which moves the screen-type lift. During the lifting operation, the lock chamber is filled with water [by the above-mentioned turbine] up to the level of the headwater. The fish-lift mechanisms are fully automatic in operation.

During 1959, 72,000 centners of fish were caught in the Tsimlyanskoe storage lake, 15 times more than in the same area of the Don River prior to the creation of the lake.

Many civil-engineering problems had to be solved during the construction of the Volga-Don Canal. Thus, the high-head concrete spillway dam was erected on easily erosible sandy soil (see Figure 51); flow from local ravines was diverted into the storage lake; the Soviet practice of erecting nonoverflow dams without any additional cofferdams was successfully followed in the construction of the Tsimlyanskaya Dam; novel pump designs of huge capacity were developed. Mechanization in the construction of this project reached a high level.

Of particular interest is the method of rapid hydraulic filling used for the first time in the construction of the Tsimlyansk HEP. The earth dam was hydraulically filled using local sand, the operation being virtually completed in a single season (1951). A ring-shaped trestle was used to carry the slurry pipeline, which carried the fill at a rate of 340,000 m^3 per day. The average monthly rate reached 5.2 m^3, markedly exceeding the monthly rate achieved at the site of the Fort Peck power plant in the U.S.A. (4 million m^3).

The great length of the earthfill dam, its distance from the sand quarry, and the high rate of hydraulic filling, required the laying of extensive pipelines for the supply of the slurry. During the most intensive period of hydraulic filling, more than 100 km of pipelines, 500 to 800 mm in diameter, were in simultaneous operation. The total installed capacity of the electric motors driving the suction dredges reached more than 75 Mw.

Features of the concrete structures of the Tsimlyanskaya HEP are the high degree of steel reinforcing used (47 kg/m^3 against 20 kg/m^3 at the Ivankovskaya HEP dam), and the smaller volume of the units in which the concrete work was done: 800 to 1200 m^3 (only seldom 2000 m^3), with an average of 600 m^3 for the whole dam and 300 m^3 for the other hydrotechnical structures. A total of 106,000 m^2 of reinforced-concrete facing shells were used, including 70,000 m^2 for the dam and powerhouse.

The Don Canal issues from the Tsimlyanskoe storage lake and, at first, follows the lowland which stretches away from its left bank. Then it sharply bends toward the south, with the irrigation channel branching off from the canal, which reaches the Don-Sal upland and continues along the Sal steppe through a tunnel of 6 km in length. The discharge capacity of this tunnel is 180,000 m^3/hr. The tunnel through the steppe was driven by a team of the Moscow Subway-Construction Trust. The work on the construction of this tunnel involved the excavation of more than 300,000 tons of material (viscous clay and sand), and the handling of 75,000 tons of tunnel linings and concrete structures. The rate at which the work was carried out was unprecendented in the history of tunnel construction. Such a rate could only be achieved by using a great deal of construction equipment. Thanks to this high level of mechanization, the canal was completed in only 3 years and 8 months (1949-1952). The following work was involved: earthmoving[41] — 174 million m^3; concrete placing — 3 million m^3; and

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masonry work — 1.6 million m^3. More than 16,000 tons of sheet piling were used and more than 44,000 tons of steel structures erected. The construction of the Volga-Don Canal involved the excavation of about 200 million m^3 of ground, and the placing of about 12,000 m^3 of concrete.

The construction of the Tsimlyanskaya HEP required a great deal of work to achieve drainage of seepage water: about 80 ha of land were drained and 10 million m^3 of water removed daily. For this, 198 movable and 180 stationary pumping stations, and 18,000 well-point filters were used. In the Volga-Don Canal project, the degree of mechanization of earthmoving was 97.9%. Concrete placing was fully mechanized. A comparison with the mechanization figures for the Moscow Canal and the Volga HEP (45% and 84%, respectively), shows the great progress made in the mechanization of construction work. For the first time, Soviet engineers used walking draglines with 40 m and 65 m booms, and 4 m^3 and 14 m^3 buckets. During 1951 the site was equipped with 11 suction dredges (each with a capacity of 500 m^3/hr). These permitted the excavation of 17 million m^3 of ground. Bulldozers excavated 16.4 million m^3 of ground, and scrapers — 49.5 million m^3 (i.e., 28.4% of the total volume of earthwork).

The construction machinery consumed about 365 million kwhr of electricity.

We shall now have a quick look at some of the effects of the industrial revolution in some of the previously backward regions of Russia. In 1913, the total installed capacity of power plants in Kazakhstan did not exceed the power of a single modern diesel engine. Kazakhstan alone now produces more electricity than all the Tsarist power plants together.

The first large hydroelectric plant built in Kazakhstan — the Ust-Kamenogorskaya HEP — was commissioned in 1953. It is the downstream stage of a two-stage cascade system on the Upper Irtysh. The project comprizes: a 65 m high concrete dam with four flood spillways, a powerhouse situated close to the dam in the tailrace, and a single-chamber ship lock of the shaft type, in which ships are lifted a height of 40 m[42].

The Irtysh Dam is higher than the Dnieper Dam, which served as a model for it. The powerhouse, including its submerged part, is equal in height to the "Moscow Hotel" in Moscow.

The volume of rock and earth excavation was 3.7 million m^3. Unlike Volga power plants, located mostly on soft ground, the Irtysh HEP was built on solid granite, only loosely covered with alluvial deposits. This is why suction dredges could not be used to any extent, these being replaced by drill rigs and subsequent grouting of the rock fissures. Instead of erecting special cofferdams to permit the construction work, special dikes were made by artificially freezing the soil. Erection and assembly work were combined by prefabricating the concrete reinforcement. Concrete was placed with the aid of movable steel platforms (trestles). The construction of the plant attracted a large number of workers from all parts of the country. The commissioning of the Ust-Kamenogorskaya HEP increased by as much as 2.5 times the power available to the industrial enterprises and mines of eastern Kazakhstan and Altai. This solved the power-supply problem of these regions. As a result, the nonferrous-mining industry increased its output more than fourfold and new ore-mining industries were created.

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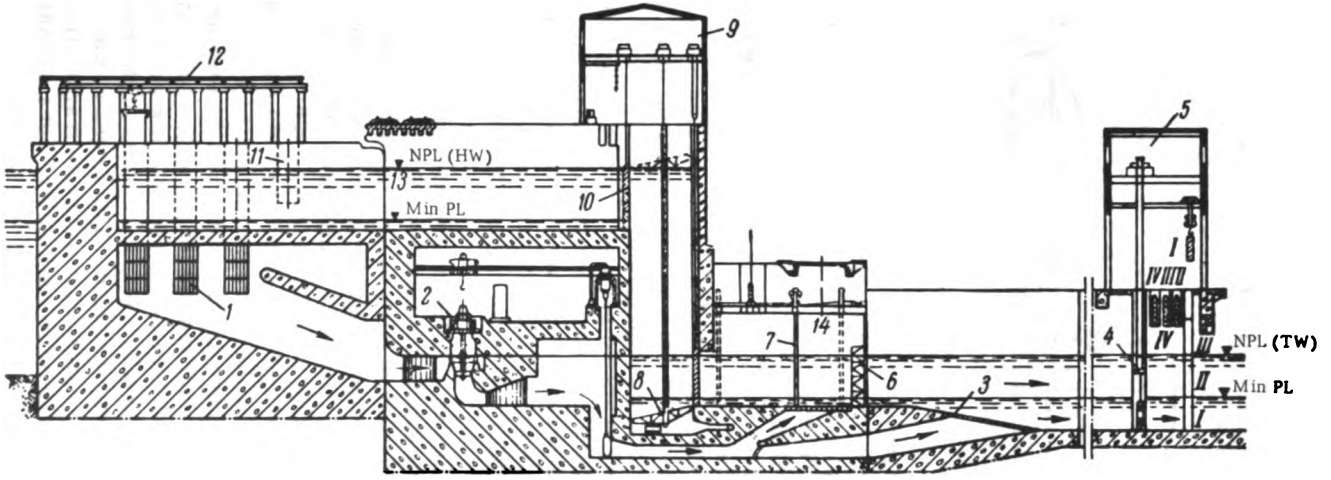

FIGURE 15. Cross section through the Tsimlyanskaya fish lift

1 – water-intakes in the upstream pier for the turbine; 2 – low-power turbine (creates an "inlet" stream for guiding the fish); 3 – stream-distribution screen; 4 – gate of the downstream flume; 5 – housing for the downstream-flume hydromechanical equipment; 6 – steel gates at the entrance to the fish pond; 7 – movable fish-guiding screen; 8 – steel lift for the lock chamber; 9 – housing for the hydromechanical equipment of the lift; 10 – stop logs (bulkheads) at the entrance to the upstream pier flume; 11 – fish outlets at the upstream pier; 12 – concrete trestle; 13 – gallery of the fish duct; 14 – gate rails (with gate); I, II, III, IV – stop logs of the downstream flume.
Arrows indicate the direction of water flow

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The Mingechaurskaya HEP in Azerbaidzhan (357 Mw) was put into operation in the fourth year of the postwar plan. The whole Soviet people participated in the construction of this plant. Novosibirskaya, Bryanskaya, and Volga plants supplied cement, the Ural Area, Donbass, and Uzbekistan sent steel, the Kramatorsk and Leningrad metal works furnished turbines, generators, hoisting equipment, etc.

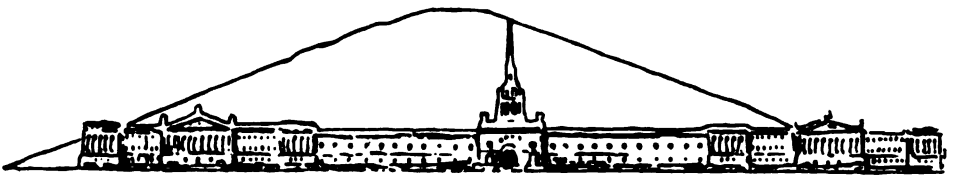

FIGURE 16. The Mingechaurskaya HEP earthfill dam shown against the Admiralty Tower in Leningrad

The construction of the Mingechaurskaya Dam was carried out under difficult geological conditions: earthwork in excavation pits — 8.8 million m^3; quarrying — 25.2 m^3; slopes and embankments ; 16.7 m^3. The earthfill dam (see Figure 16) was not erected on a conventional foundation but on a hydraulically filled bed of 15 million m^3 volume (sand and gravel). The excavation of such huge quantities would have represented more than 3 million railroad carloads (Figure 57).

Hydraulic filling of the Mingechaurskaya Dam was carried out without any trestle for the slurry pipeline. A daily filling rate of up to 20,000 m^3 was reached. In this new method, the slurry pipeline is located directly on the body of the dam; it thus permitted savings of more than 10,000 m^3 timber and reduced to a considerable extent the time required for construction and the number of personnel required. The use of this method disproved foreign contentions, due to, i.a., the Italian engineer Omodeo, that the erection of a high earthfill dam on a fine-sand foundation was impossible.

The volume of concrete placed at the Mingechaurskaya HEP was 1 million m^3 (the same as that placed in building the Dnieper HEP.

The construction of the Kakhovskaya HEP was mainly intended to create a new generation block and to improve navigation conditions on the lower Dneiper — from the Dnieper Dam down to the Black Sea. The Kakhovskaya HEP was the first Soviet station to be erected on loess. The power scheme consists of a powerhouse, concrete spillway dam, nonoverflow earth dam, navigation lock, and water intake for the Krasnoznamenskii irrigation canal.

The powerhouse of the plant (Figure 17) is of the built-in type and is provided with sluiceways, which permitted the length of the spillway to be reduced by 70 m. A feature of this plant is the use of a low draft tube which allowed the depth of the construction pit, as well as of the basic construction work, to be considerably reduced. The floors of the submerged part of the powerhouse consist of reinforced-frame structures. This gave savings in the timber needed for scaffolding, but increased the requirements of reinforcing steel by 20 to 26%.

The concrete gravity dam has a length of 450 m and is provided with 28 spillway openings. The rated specific water discharge at the downstream

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floor (apron) is 45 m^3/sec, while the actual (measured) discharge is 61 m^3/sec.

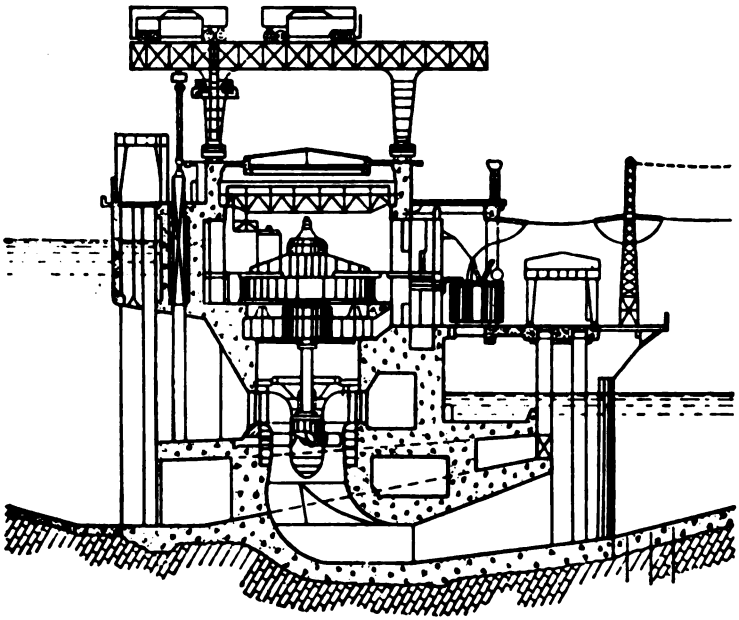

FIGURE 17. Cross-sectional view of the Kakhovskaya HEP powerhouse with sluiceways

The earthfill dam, made of fine sand, has a height of 30 m and a length of 1300 m. It crosses the main channel of the Dnieper River between the powerhouse and the locks.

The "Kakhovskoe Sea" created by the dam has a volume of 18.2 billion m^3, an area of 2155 km^2, a width of up to 20 km, and a length of 240 km.

The six 46 Mw [sic] Kaplan turbines of the plant give a total installed capacity of 312 Mw, four times the capacity of the Volkhovskaya HEP, and an output of up to 1.4 billion kwhr.

The construction of the plant involved 35 million m^3 of earthwork, 1.5 million m^3 of concrete placing, and the laying of nearly 200 km of railroad track.

Concrete work was considerably speeded up by the extensive use of prefabricated concrete reinforcing and precast monolithic concrete blocks. The average weight of such a block was 8 to 10 tons. The volume of such a block was increased from 500 — 600 m^3 to 7000 — 8000 m^3, and their surface area to 1100 m^2.

The first turbine unit of the Permskaya HEP was commissioned in 1954. The powerhouse of this plant is incorporated in the 400 m-long concrete dam which is divided by piers into 24 spillway bays. Each of the piers

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contains a single turbine unit. This type of built-in powerhouse reduces the volume of concreting to half that required for conventional power plants (see Figure 59).

Many engineering problems had to be solved during the construction of the plant. Thus, the lock walls were made of steel sheet piling instead of conventional concrete slabs. The piles were driven into the soil by a novel more efficient method — using electric vibratory pile drivers. The turbines were put together in the assembly bay and then installed by powerful cranes, as 150 ton units. This method reduced the time required for installation of each turbine unit by 15 days. The construction of the Permskaya HEP involved 15 million m^3 of earthwork, including more than 9 million m^3 of hydraulic filling, 65% of which was carried out by mechanical methods. During the hydraulic filling of the run-of-river dam (2.5 million m^3), material was taken simultaneously from two sources which provided soil of different fractional composition (size distribution). The downstream toe of the dam was filled with a sand-gravel mixture, while the upstream toe contained sand only.

During the period of the fifth Plan, construction work started on the following hydropower projects: the Volgogradskaya Plant on the Volga, Kremenchugskaya on the Dnieper, Votkinskaya on the Kama, Novosibirskskaya on the Ob, the second Bukhtarminskaya on the Irtysh, Irkutsk on the Angara, Khramskaya No. 2 on the Khrami, Nizhne-Khramskaya No. 1 Plant on the Lower Khrami (in Georgia), Alma-Atinskaya No. 2 in Kazakhstan, the Alamedinskaya plants Nos. 5 and 6 on the Chu in Kirgizia, Kaunasskaya Plant in Lithuanian SSR, etc.

The construction of the first "super" hydropower plant in Siberia (the Bratsk Plant) started in 1955. It was intended "to promote all aspects of industry in this area"[43].

More than 40 hydroelectric plants were under construction, toward the end of the fifth Five-Year Plan, their total installed capacity exceeding by a factor of almost two, the total installed capacity of the USSR in 1954. The construction of such a large number of plants involved a tremendous amount of work: 774 million m^3 of earthwork, 16 million m^3 of concrete, and 880,000 tons of steel-structure erection (see also Table 18, page 99). Mechanization was widely used in carrying out this work. Most of the construction work was done using Soviet-built equipment: large bucket excavators (3 m^3 buckets), walking excavation draglines (bucket capacities 3, 4, and 14 m^3) dump trucks of up to 25 tons, large electrically driven suction dredges with a capacity of up to 1000 m^3, etc.

Automated concrete-mixing plants were used for the first time on the construction of the Volga-Don Canal in 1950-1951. The use of such plants, equipped with 1200 and 2400 l concrete mixers, is now standard practice on Soviet construction sites, e.g., they were used in building the Verkhne-Svirskaya, Narvskaya, Gorkovskaya, and Volga plants. At the beginning of 1955, fifty-eight concrete mixing plants, with a daily output of 65,000 m^3 of concrete, were working on various hydroelectric-station construction sites.

Aggregate for concrete mixing was obtained from 13 large mechanized stone and gravel quarries, which gave a yearly output of 10 million m^3 of construction material.

From the concrete-mixing plant the mix is transferred to the construction site by special cranes: tower cranes with a lifting capacity

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of 15 tons at maximum boom extension, gantry cranes of capacities up to 10 tons, and various crawler cranes. Special concrete pumps (with a delivery of 40 m^3/hr), designed by Soviet engineers, fed the mix from the plant to the cranes.

Automating hydroelectric stations

The directives of the XIX Congress of the CPSU for the fifth Five-Year Plan stressed the necessity for further work on automation in hydropower plants. In line with these directives, automatic control had been introduced into all the regional hydropower plants by the end of 1953. Remote control was given particular attention as being a further step toward complete automation (see Figure 18).

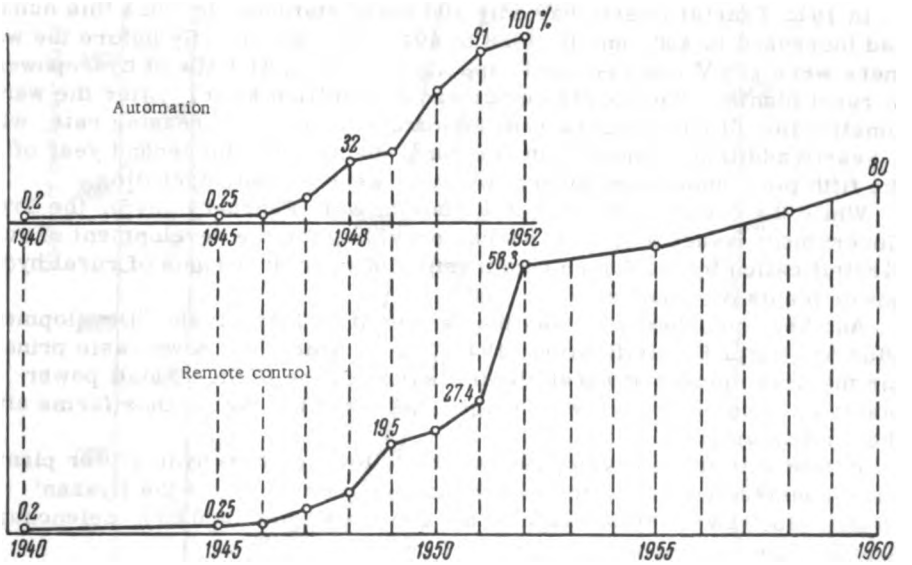

FIGURE 18. Introduction of automation and remote control into hydropower plants in the USSR during the period 1940 and 1960 (automated equipment as a percentage of the total installed capacity).

During the fifth plan the number of remotely controlled hydropower plants increased from 14 to 60. Whereas in 1950 only 22.2% of turbine units and other plant equipment was remotely controlled, by 1955 this percentage had increased to 65%.

But remote control and automation of individual plants is only the first step toward the automation of complete power systems, which is now an urgent task. The power system of Uzbekistan, which has 14 automated plants, including seven without any operating staff, is equipped with a central load-dispatching station controlling plants situated at distances of up to 170 km. Plans are being worked out for the remote control of the

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Mingechaurskaya HEP (in the Caucasus), from a central station in Baku (Azenergo). Other central stations are controlling the Chirchik cascade of power plants, the Niva and Varzobskaya plants, etc.

In many hydroelectric plants the number of operating staff could be reduced by 42 to 68% by the introduction of comprehensive automation.

SMALL HYDROELECTRIC POWER PLANTS

Rural electrification constitutes an inseparable part of the general plan of electrification of the Soviet national economy. During the postwar period the erection of rural power stations was not neglected.

Before 1917 the total installed capacity of rural power plants did not exceed 2 Mw — the power of a modern kolkhoz power plant. The October Revolution had a strong impact on the development of rural electrification (Figure 19).

In 1913 Tsarist Russia had only 100 rural stations; by 1924 this number had increased to 450, and by 1928 to 694. In 1940, shortly before the war, there were 265 Mw of installed capacity (including 31.6 Mw of hydropower) in rural plants. The yearly output was 300 million kwhr. After the war construction of rural plants went forward at an ever-increasing rate, with a yearly addition of more than 100 rural plants. By the second year of the fifth plan, more than 2000 new plants were already operating.

While the country was still in a state of war (February 1945), the Soviet Government issued a special decree providing for the development of rural electrification by the future constructing of many thousands of rural hydropower plants on small rivers.

Another important step was the decree of 29 May, 1948, "Development Plan for Rural Electrification, 1948-1950", which laid down basic principles for the development of rural electrification in the USSR. Small power plants of 50 to 100 kw were no longer sufficient for the kolkhoz farms after their amalgamation.

In line with these developments, the following rural hydropower plants were constructed during the fourth plan: Kuzminskaya in the Ryazan' Region (1000 kw), Servanskaya in the Odessa Region (600 kw), Zelenchugskaya in the Stavropol Territory (415 kw).

The fulfilment of the target figures meant that, by 1950, the installed capacity of rural plants had increased eight times, compared with the prewar level [1940], reaching 243 Mw.

During the next plan, work continued on the extension of the rural hydropower plants. The number of rural plants increased to 17,000 with a total power of 1100 Mw (including 600 hydropower plants representing 230 Mw). The share of hydropower in the total power production markedly increased: in 1955, 25% of all rural power was produced at hydroelectric stations. The growth of hydropower construction has been accompanied by an increase in average station power. During the period 1940 to 1955, the number of hydropower plants increased by a factor of 6.15, and the average station power by a factor of 13, reaching 70 kw per plant. During the period 1940 to 1955 many small hydroelectric plants were closed down because of their low efficiency. Although the total number of plants was reduced, the total installed capacity increased, since the generating capacity of medium and large rural plants was expanded.

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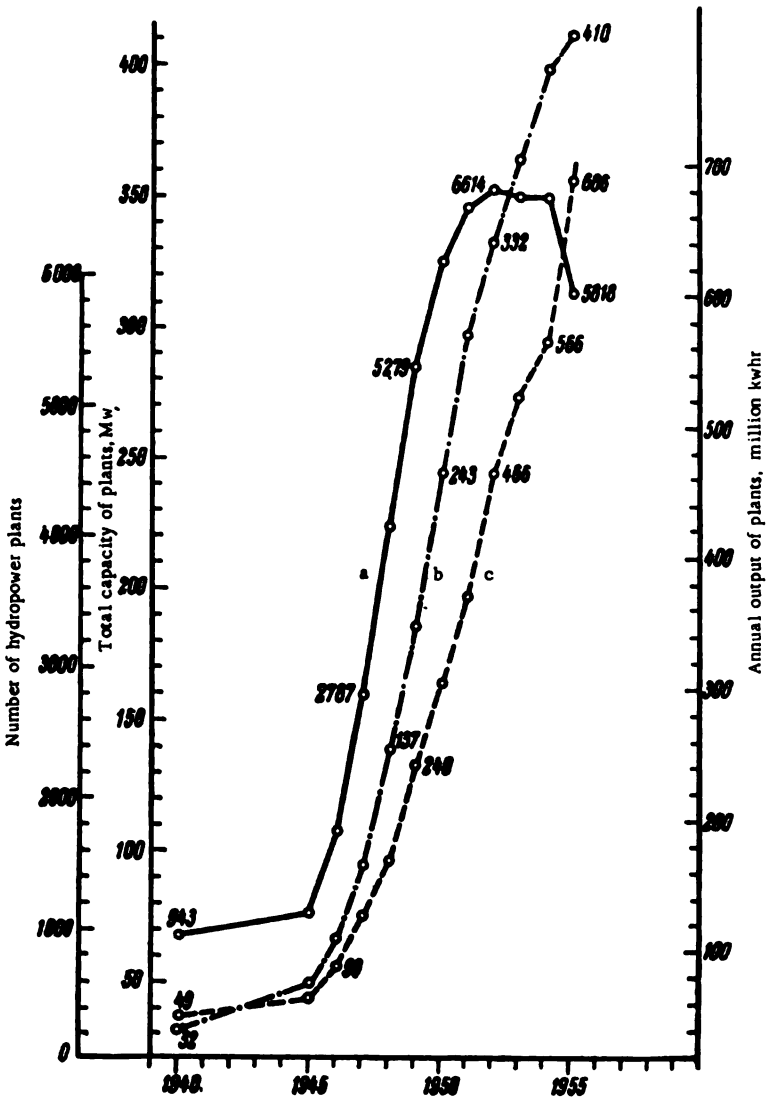

FIGURE 19. Construction of small hydroelectric power plants (1940 to 1955)

a — number of rural HEPs; b — plant capacity, Mw; c — annual output, million kwhr

During the same period the annual number of hours of effective utilization of hydroelectric capacity increased from 1544 (in 1940) to 1699 (in 1955). This relatively low level of utilization shows that the character of the load demands on HEPs is almost the same as for thermal power plants, for which the corresponding figure is 1483. Many small rural hydropower plants do not have a sufficient water reserve. Therefore, in designing new rural plants, much attention is being given to the creation of sufficiently large storage lakes which ensure the power supply to both residential and industrial users.

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By 1948 a third of the rural HEPs served the large kolkhoz farms. Thus, in the Ryazan Region alone more than 250 HEPs were constructed. Among these were the Kuz'minskaya station on the Oka River, the Dankovskaya on the Don, and the Ten'syupinskaya on the Tsna, each of about 1000 kw. The largest of the rural HEPs, the 2 Mw Rassypukhinskaya Plant, constructed jointly by 61 kolkhoz farms, serves 130 villages, 532 cattle-raising farms, 110 agricultural centers, and 12,000 housing units on kolkhozes.

The Sverdlovsk Region was the first in the USSR to achieve 100% rural electrification, the Moscow Region being the second.

Practical experience proved the expediency of interconnecting small rural plants to local power systems[44]. Such systems exist in the Perm and Leningrad regions. Eleven local rural systems exist in the Ukraine; the largest of these was created in 1953 in the Korsun-Shevchenkovskii Region. It links four rural HEPs with a total capacity of 5850 kw. In 1958 the length of transmission lines belonging to this system was 1010 km. About 80% of the turbine units connected to this network are automatically controlled. The network supplies electricity to 118 kolkhozes, nine regional tractor stations, six regional power centers, and 45 local industrial establishments. In 1958 this network provided 33.7 million kwhr.

The financial share of kolkhozes in the construction of rural plants increased considerably. In 1954, 17 kolkhozes in the Vinnitsa Region (on the southern Bug River) contributed to the construction of the 400 kw Chernyatskaya HEP. The kolkhoz HEP "Druzhba narodov*", was erected at the meeting point of the boundaries of Belorussia, Lithuania, and Latvia.

In recent years the possibility has been studied of connecting these local networks to the state power systems, and of constructing still larger rural plants. In this connection the following large rural HEPs have already been commissioned: Orlov (2400 kw), Tiripon in Georgia (4000 kw), the Novo-Troitskaya HEP in the Stavropol Territory, etc.

The Kuban-Yegorlykskaya Canal system, intended for the irrigation of the Stavropol' steppe, and fed from the Kuban River, led to the construction of a large storage lake (area 18 km^2) near the Novo-Troitskaya station. This lake was used in 1954 to feed the 3680 kw newly erected Novo-Troitskaya HEP. This plant supplies electricity to 26 kolkhozes, nine tractor stations, three sovkhozes, two factories, 30,000 houses, and 500 electric motors.

In constructing new rural hydropower plants, existing dams and ponds are utilized. This gives large savings in capital cost. (A large part of the cost of such projects is due to the dams.) According to statistical data, Soviet rivers have more than 40,000 dams which can easily be adapted to meet the needs of power generation. Twice as much electricity as is now obtained from the Dnieper HEP could be obtained in this way.

Special storage lakes will be formed to increase the water reserve of hydropower plants by accumulating spring discharge and providing it for power generation. As an example of such yearly-runoff regulation, mention may be made of the earth dam in the village of Sheptukhovka on the Kalitva River in the Rostov Region. This dam, which has a height of 16 m, created a storage lake with a volume of 28.5 million m^3, giving an annual average discharge of 0.83 m^3/sec. If the plant operates daily for 8 hours, the storage lake gives an average discharge of 2.5 m^3/sec. The lake also

* ["Friendship among Nations".]

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caused a marked improvement in the operating efficiency of other power plants located downstream.

In 1960 there were 83,284 rural power plants in operation. These had a total capacity of 3676 Mw, producing 6 billion kwhr annually. More than 4% of these plants are hydroelectric stations, with an installed capacity representing 11% of the total. Rural electrification is not based on the supply from rural plants alone. Increasing use is being made of the state power systems.

HYDROPOWER CONSTRUCTION, 1956-1958
THE VOLGA HEP im. LENIN

The XX Party Congress, held in February 1956, set out the outlines for the sixth Five-Year Plan[45], and the target figures for power construction in general, and specifically for hydropower.

The directives of the congress provided for the completion of the world's largest HEPs, Kuibyshevskaya and Volgogradskaya, and the subsequent harnessing of the Volga, Kama, and Lower Dnieper rivers, the construction of hydropower plants in the western and central Asian regions of the USSR, and in the Caucasus.

A feature of the new plan was the stress laid on power construction in the eastern regions, particularly in Siberia, which has virtually unlimited water-power resources.

Apart from the large hydropower plants to be erected on the Irtysh, Angara, and other Siberian rivers (as described earlier), construction started of the following hydropower plants in Central Asia: Khishrauskaya on the Zeravshan River, Perepadnaya on the Vakhsh, the Kairakumskaya on the Syr Darya, the Uchkurganskaya on the Naryn River, etc.

The extraordinary congress of the CPSU, held in 1959, prepared the target figures for the seventh plan.

The increase in power production for the years 1956 to 1958 is shown in Table 16.

TABLE 16
Development of power production during the years 1956-1958

	Year			
	1955	1956	1957	1958
Output by all power plants, billion kwhr ...	170.2	191.6	209.6	235.3
Output of HEPs, kwhr	23.1	28.9	39.4	46.5
Percentage due to HEPs	13.6	15.1	18.8	19.8

The yearly output increment during this period exceeded the yearly increment of all the preceding Five-Year Plans, as can be seen from the following figures: 1956 — 21.4 billion kwhr, 1957 — 18.0 billion kwhr, 1958 — 25.6 billion kwhr. In 1958 Soviet power plants produced a total of 235.3 billion kwhr, i.e., more than was produced by France, Italy, and Sweden.

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In 1957 the installed capacity at hydroelectric stations reached 10 million kw and the total output 39.4 billion kwhr, or 18.8% of the total output of the USSR. Compared with 1956, the increment in output increased by 17.5 billion kwhr, 57% of this being due to the operation of the first turbine units of the Volga HEP im. Lenin. The first unit of this plant started to operate in December 1955; in 1956 11 other units were commissioned and, by the end of 1957, the last of the units was under load[46]. In October 1957 the power plant reached its rated capacity.

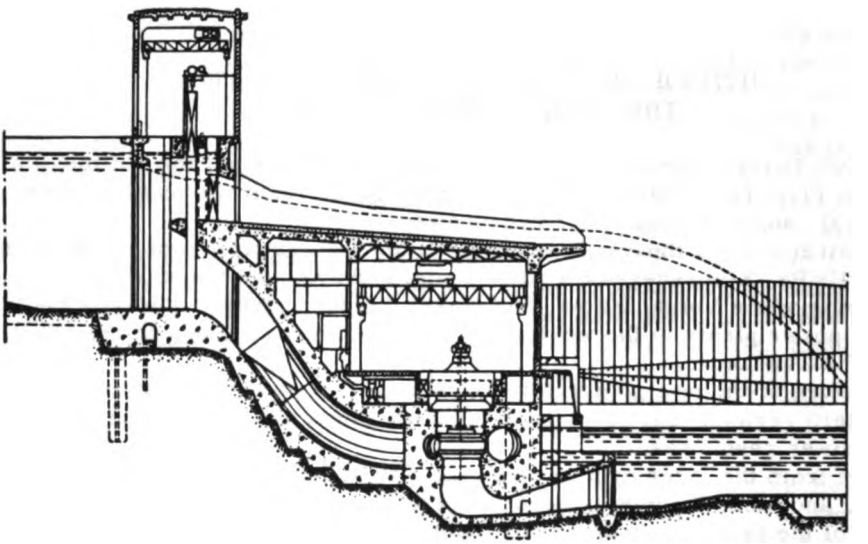

FIGURE 20. Low elevation hydropower plant; the water spills over the top of the powerhouse (Knyazhegubskaya HEP in the Arctic Region).

Toward the end of 1958, the introduction of new capacity advanced at an ever-increasing pace: a series of large plants — the Gorkovskaya, Kakhovskaya, Gyumushskaya, Niva No. 3, Verkhne-Svirskaya, Knyazhegubskaya, Irkutskaya, and Novosibirskaya HEPs — started to operate at full capacity.

The Knyazhegubskaya HEP (see Figure 20), which harnesses the largest river in Karelia — the Kovda River — is very interesting for its topographical location. The plant is located 30 km from the river bed in a narrow strip of land 4.5 km wide, that separates Lake Kovdo from the Knyazhaya Guba inlet of the White Sea. The head (36 m) is created by a diversion channel 1.5 km long which intersects the isthmus. The 17 m high dam creates a small storage lake. The discharge is removed through a 600 m tailrace channel.

The construction of the Gorki Hydro development — the first stage of the Volga-cascade plants — started in 1948; the plant was commissioned at its rated capacity on 24 December, 1956. The construction of new plants solved the complex problem of utilizing one of the most important stretches of the Volga for power generation and transportation. The mean annual

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guaranteed capacity of the plant is 400 Mw and the output for a medium annual runoff is about 1.5 billion kwhr.

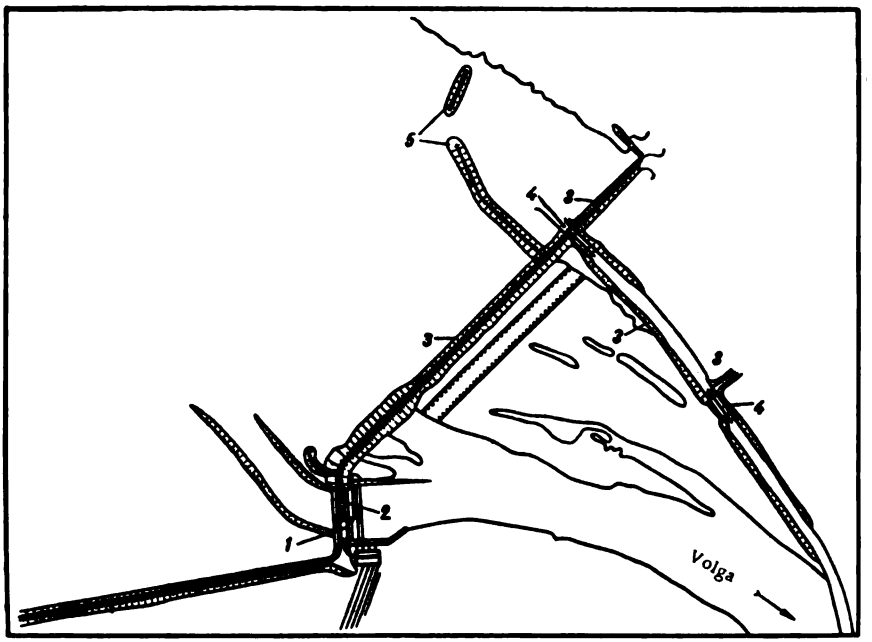

FIGURE 21. Layout of the Gorki hydrodevelopment:

1 — powerhouse; 2 — spillway dam; 3 — navigation lock; 4 — protection dike (levee)

The site of the HEP is located upstream from the town of Gorki near the town of Gorodets (Figure 21). The total length of the water-retaining structures crossing the bed of the Volga is 16.3 km. The development comprises a powerhouse located in the river bed adjoining the concrete spillway dam (which is equipped with 20 m spill bays, each for a discharge of 16,000 m^3/sec). On the left the dam adjoins the 1200 m long run-of-river earthfill dam. Large earth dikes on the river banks, of total length 11 km and volume about 23 million m^3, ensure proper protection of the structures. The lock is of the two-stage type with two lanes. In front of the locks are protecting jetties to permit changes in the composition of the train of ships passing through, and to provide harbor facilities for use during storms.

The Gorkovskaya HEP raised the level of the Volga by 17 m. The storage lake created by the dam has an area of 1600 km^2 and a volume of 8.7 km^3 (useful volume — 2.8 km^3), sufficient for seasonal regulation of the runoff of the Volga which, at this site, reaches 54 km^3 per year. The powerhouse building is of semi-outdoor type. In the floor of the machine room above each turbine unit, are special hatches through which the crane (capacity 500 tons) can lower the various machines into the machine room. The eight Kaplan turbines of the plant, each of 59 Mw, were supplied by the Leningrad Metal Works. The turbine water wheel has a diameter of 9 m (see Figure 66).

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All the earthfill structures [dams and dikes] were made using locally available sand and filled by hydraulic sluicing.

The volume of earthwork at this plant was about 60 million m^3; concrete work did not exceed 1.6 million m^3. The amount of reinforcing steel used was also relatively low — 38 kg/m^3 (including the concrete for the locks). The arrangements for groundwater drainage proved to be ineffective; the excavation work for the powerhouse pit (and later for the downstream toe of the spillway dam) was done under the protection of an ice-permafrost soil curtain, which penetrated 14 m below the powerhouse foundation. The excavation of the construction pit (1.5 million m^3) took only six months.

The steel piles forming cellular cofferdams, which were in use during construction, were installed for the first time in the Soviet Union using a vibration technique. About 4000 tons of steel piles were driven to a depth of 15 m by this method.

Extensive use was made of large reinforced concrete blocks (sometimes weighing 70 tons). These blocks were cast on the site, and were used in the powerhouse assembly bay, headwater piers, etc. Concrete placing was carried out throughout the year. During the winter the concrete mix was heated electrically. The so-called peripheral method of heating made it necessary to use special means for heating the formwork. In this new method, electrodes are spaced every 20 to 30 cm along the formwork, and connected to a source of current. During the winter 1953/4, this method was used for heating 117,000 m^3 of concrete mix. All the eight turbine units were installed in 13 months (November 1955 to December 1956).

The increasing rate at which power construction was carried out during the years 1956 to 1958, was due to improvements in design and to the higher pace achievable when building cascade-type plants (rather than isolated plants).

Table 17 shows the advantage of constructing large plants instead of small ones.

TABLE 17

Investment in hydropower construction as a function of plant capacity

Plant capacity, Mw	Less than 100	101 to 200	201 to 1000	More than 1000
Cost per Mw of installed capacity, %	100	84	80	64

The stress laid on the construction of power plants in the eastern regions steadily raised the average capacity of the newly erected plants. In 1940, the average capacity of new hydropower plants was 80 Mw. During the period 1941 to 1950 it was 175 Mw, and during the period of the fifth plan, construction started of plants having capacities of up to 400 Mw. Such a capacity, which was then so impressive, is today merely average.

In 1940 the capacity of the largest hydropower plant was 434 Mw. In 1958 it was 2300 Mw. In 1957 the Volga HEP im. Lenin was run for the first time at full power and, in December 1958, the first unit was commissioned at the still larger Volga Plant — the plant bearing the name of the XXII Party Congress (2563 Mw).

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Giant hydropower plants are now being built on the Angara River (the 4500 Mw Bratsk HEP) and on the Yenisei River (the 5000 Mw Krasnoyarskaya HEP). These figures are much ahead of the corresponding figures for the U.S.A. where the largest hydropower plant is of 2000 Mw only (see Figure 74). In the U.S.A. the average capacity of existing hydroelectric plants is 14 Mw; for those now under construction the figure is slightly more than 100 Mw.

After a series of plants was put into operation during the period 1956 to 1960, 90% of the total hydropower output was contributed by plants of 100 Mw or more.

The installation of large hydraulic turbine units gives large savings in means and time. This is easily seen from the installation of turbine units of increasing capacity — from the 16 Mw units of the Volkhovskaya HEP to the 72 Mw units of the Dnieper HEP, and the 126 Mw units of the latest Volga HEPs.

At the World Fair in Brussels in 1958, Soviet hydraulic turbines received honorable mention.

The advance to large turbines was made possible by the ever-increasing expansion of turbine construction, the erection of 220 kv and 400 kv lines, which permit the transmission of current over distances of more than 1000 km, and the creation of large interconnected power systems to which the large power plants are linked. Connection to large power systems permits better utilization of a plant's capacity and also improves the efficiency of the power system.

Another characteristic feature of power construction is the increasing tendency to adopt a cascade arrangement of power plants on the most important Soviet rivers.

Thus, in 1958, work continued on the setting up of the Volga, Kama, and Dnieper cascades in the European part of the USSR and the Angara and Yenisei cascades in Siberia.

Priority was given to the construction of the Volga and Kama cascades to ensure adequate power supply for the industrial development in the adjoining areas.

In 1956 the Gorkovskaya HEP on the Volga was completed to full capacity (400 Mw) and the last of the 23 turbine units of the Permskaya HEP (500 Mw) was commissioned. Twelve of the units had been under load since earlier in the same year. In November 1957 the official opening of the Volga HEP im. Lenin took place. In the same month the cornerstone was laid for the construction of the Votkinskaya HEP on the Kama River. The first turbine units of another Volga giant — the Volga HEP im. XXII Party Congress — started to supply current.

The lower stage of the Dnieper cascade system — the Kakhovskaya HEP (312 Mw) — was put under full load. At the same time, construction was in progress on three other plants of the cascade: Kremenchug, Dneprodzerzhinsk, and Kiev.

Other hydropower plants were also commissioned: the Ondskaya on the White Sea-Baltic Sea Canal; the Knyazhegubskaya on the Kovda River beyond the Polar Circle, the Tereblya-Rikskaya in Transcarpathia[47], the Khishrauskaya in Uzbekistan; the Arzninskaya (the fourth stage of the Sevan-Razdan cascade) in Armenia; the Varvarinskaya on the Kura River; the Tkibul'skaya, Gamutskaya No. 2, and Bzhuzhskaya plants in Georgia.

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The Ortachal'skaya HEP in the Tbilisi Region was commissioned to full capacity. This was the first Soviet station to be equipped with tubular (horizontal) turbines installed in the spillway-dam piers.

In 1958 construction continued of Gamutskaya No. 1 station on the Rion River and the underground plants, Landzhanurskaya and Khramskaya No. 2. The latter has a 13 km water-supply tunnel, the longest tunnel in Transcaucasia[48].

Not far from the town of Leninabad at Kairak-Kum[49], where the water-rich Syr Darya turns sharply to the right, the largest hydroelectric power station in Soviet Central Asia started to export electric power. The Kairakumskaya HEP was given the name "Druzhba narodov*", not only because it supplies power to the industry of three republics — Uzbekistan, Tadzhikistan, and Kazakhstan, but also because people from all these republics participated in its construction. This plant is of the utmost importance in the electrification and industrialization of these areas (Figure 48).

The layout of this plant somewhat resembles that of Permskaya HEP: the powerhouse is built in the spillway dam. All the six turbine units were commissioned in January 1958. The development consists of a 126 Mw plant and the largest storage lake in this part of the USSR, the so-called "Tadzhik Sea", which has a length of 60 km, a width of 20 km, and a volume of 4 billion m^3. This lake was created by impounding the waters of the Syr Darya River which is fed from the glaciers of the Kuramin mountains. The lake feeds the turbines of Kaizakumskaya and Farkhadskaya HEPs, and irrigates vast areas of these three republics. A new town is growing up in the famous Golodnaya Steppe [Bet-Pak-Dala], surrounded by numerous farms and industrial establishments. The lake is also a rich source of fish.

In the erection of the Kuibyshev hydro development on the Volga near Zhiguli, the experience gained in the construction of other Soviet HEPs, Volkhovskaya, Dnieper, Svirskaya, etc., was applied.

The Volga HEP im. Lenin, which is a part of this scheme, was officially inaugurated on 10 August, 1958. The influence of the GOELRO Plan on the way in which Soviet power construction developed was appreciated by Soviet leaders[50].

In the construction of the Dnieper HEP, the Soviet Government had to import foreign equipment and to resort to the help of foreign consultants and constructors. Subsequent large projects on the Volga and other rivers were carried out solely by Soviet designers and machine builders and were equipped with Soviet machinery.

The construction of the Volga HEP im. Lenin [sometimes called the Kuibyshevskaya HEP] marked an important step forward in the creation of the material basis for communism[51].

The construction of the Volga HEP also marked a new stage in hydropower construction: this was the first power plant designed for a discharge [as high as] 85,000 m^3/sec (spring high water) to be erected on sand and clayey ground. The total length of the water-retaining structures (including the powerhouse, the earth dam, and the spillway dam) is 5500 m.

* ["Friendship among Nations."]

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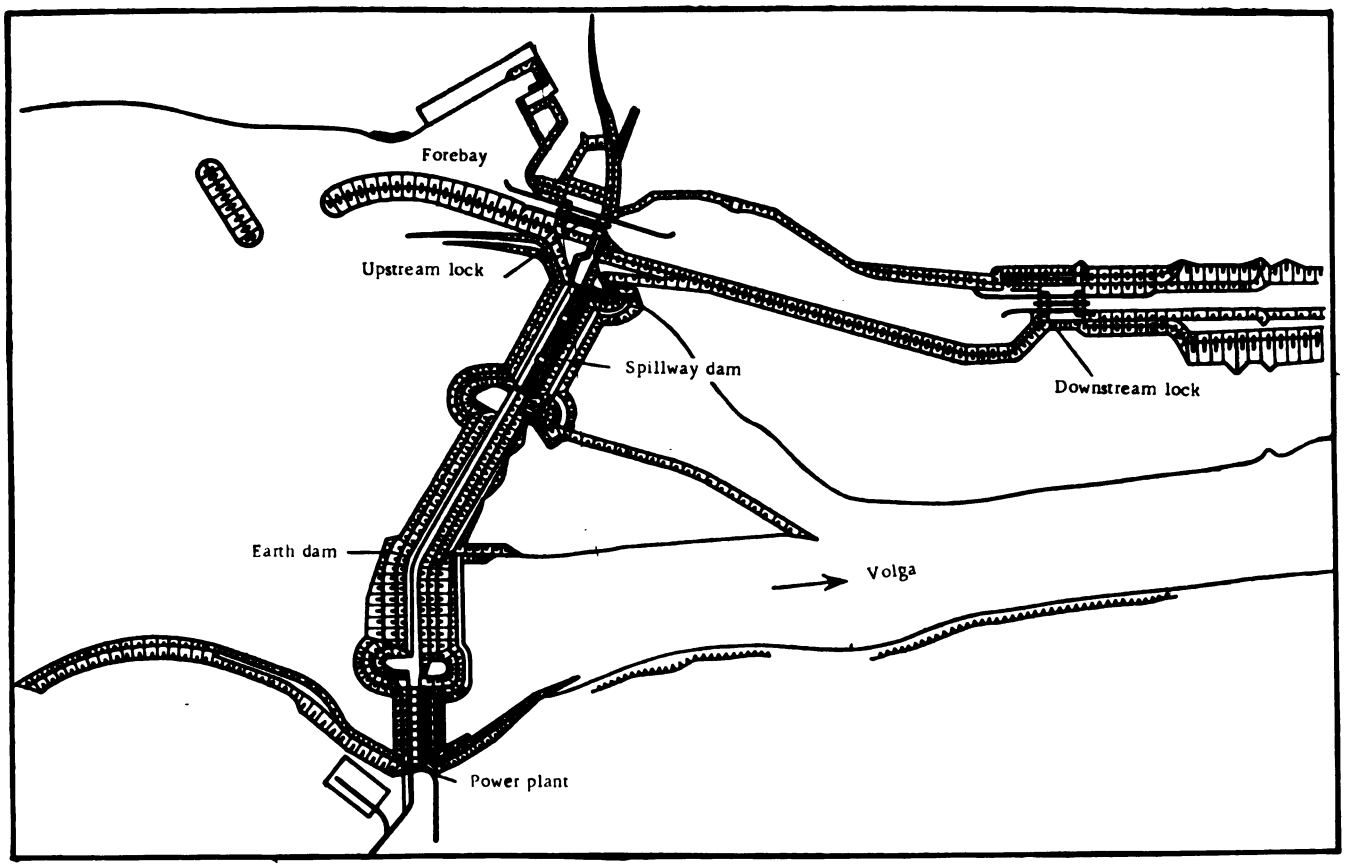

FIGURE 22. Layout of the Volga HEP im. Lenin

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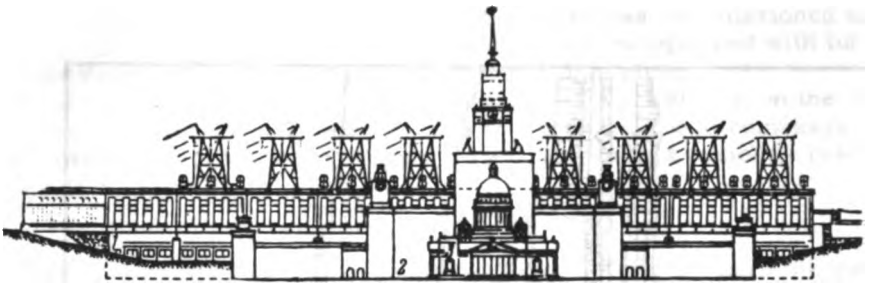

FIGURE 23. The powerhouse of the Volga HEP im. Lenin (volume 4.5 million m^3) shown against the Moscow University im. Lomonosov (2.6 million m^3) and the St. Isaac Cathedral (31 million m^3)

The two stages of the single-chamber twin locks are separated by a forebay 2.8 km long. The upper locks operate under a head of 10 to 14.6 m, and the lower ones under a head varying between zero and 14.6 m; at maximum high water the level of the lower pool rises to the level of the intermediate pool.

The concrete powerhouse, 81 m high and 128 m long, has a foundation 50 m deep. The volume of concrete used in the powerhouse was 3.1 million m^3. The total volume of the powerhouse is 4.5 million m^3 (see Figure 23). The area of the excavation for the power plant, together with the adjacent inlet and outlet channels, was 40 ha. The site, which was surrounded by cofferdams, reached a depth of 45 m in the river-bank section, and 20 m in the river bed. Excavators, working 30 m below the water level of the Volga, removed 12 million m^3 of clayey soil.

The powerhouse contains 20 turbine units and 80 sluiceways for water discharge. The total discharge through the water-outlet structures of the plant is 30,000 m^3/sec. Housing the turbine units in a structure which also contains the spillways (above the draft tubes) permitted the length of the spillway dam to be reduced by a third of its [original] design length; the volume of concrete necessary was reduced by 800,000 m^3.

The spillway dam with its 38 bays has a discharge capacity of 66,000 m^3. The earth dam was filled from locally available sand by hydraulic-sluicing methods. Its maximum height is 45 m and its volume is about 30 million m^3.

The Kuibyshevskoe storage lake, also known as the "Zhiguli Sea", has a volume of 58 billion m^3, much more than that of Lake Mead in the U.S.A. (43.7 billion m^3), considered to be the largest artificial lake in the world (Figure 49).

In terms of the rate at which construction proceeded, and the volume of work involved, the figures for the Volga HEP im. Lenin are larger than for many of the biggest hydro developments in the world (see Table 18).

Construction of the plant began in the second half of 1950; the first turbine unit started to operate on 29 December, 1955, and the last (the 20th unit) on 14 October, 1957.

The dam across the Volga was constructed from a floating bridge. At that time, the river bed had its narrowest section near the left bank; the floating bridge was moved toward the dam. An earthfill dike was erected close to the right-hand (Zhiguli) bank. The gap between the dam and the dike was 350 m; this narrowing of the river bed almost doubled the velocity of the water flow.

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TABLE 18

Earthmoving and concrete placing in the construction of various large hydroelectric power plants

Power plant	Constructed	Concrete volume, 1000 m³	Maximum rate of concrete placing			Volume of earthwork	Maximum rate of earthwork, 1000 m³		
			yearly	monthly	daily		yearly	monthly	daily
Panama Canal	1907-1913	3860	–	–	3.4	162.0 (66 dredges)	28,000 (1908)	2280 (1908)	61.0 (III. 1911)
Dnieper HEP	1927-1932	1180	518 (1930)	110.6 (X. 1930)	5.38	6.4 (0.6*)	–	100.5* (1932)	4.0
Bagnell, U.S.A.	1930-1931	423	420 in 10 mths of 1930	85.0 (VI. 1930)	–	–	–	–	–
Moskva-Volga Canal	1932-1937	2957	1407 (1936)	170.0	10.0	143.2 (11.0*)	53,900 (4588* X 1936)	–	7920.0
Boulder Dam, U.S.A.	1933-1936	3060	1400	201.0	8.0	5.3	–	–	–
The Volga power plants comprising:	1936-1941	2090	801	102.2	9.75	48.0 (11.4*)	13,500 (1937)	–	–
Rybinsk	–	1400	544	70.4	5.4	–	–	–	–
Uglich	–	690	257	31.8	4.35	–	–	–	–
Grand Coulee Dam, U.S.A.	1934-1941	8100	1700	377.0 (X. 1939)	15.7	15.8	–	–	–
Fort Peck, U.S.A.	1934-1939	–	–	–	–	76.51	–	4000*	–
Shasta, U.S.A.	1940-1944	5000	1560	152.0	9.0	–	–	–	–
Volga-Don Canal Scheme	1948-1952	2960	1980	252.0	12.5	174.0 (51.0*)	95,500 (1951)	14,000	540.0 (1951)
including Tsimlyansk	–	1960	1266 (1951)	153.0	8.97	92.0 (44.0*)	49,000 (28,000*)	5200*	340.0*
Hungry Horse, U.S.A.	1949-1952	2300	–	190.0	6.5	–	–	–	–
McNairy, U.S.A.	1947-1954	1420	–	191.0	8.0	2.0	–	–	–
Volga HEP im. Lenin	1950-1957	7671	3134 (1955)	389.3 (VIII. 1955)	19.05	193.9 (107.8*)	50,000 (28,000*)	7630 (4900*)	420.0 (300.0*)
Kakhovskaya HEP	1950-1955	1420	668 (1954)	80.0	4.5	30 (26*)	8506 (1955)	(IX. 1955)	–
Volgogradskaya HEP	1954-1960	5870	1896 (1957)	186 (1957)	10.7	148.0**	21,635* (1958)	–	–
Bratskaya HEP	1958-1963	4800	1600 (1961)	150 (V. 1961)	6.6	12.8	9200 (1959)	–	–

* Hydraulic filling

** Earth levelling and compacting

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The floating bridge was supported by steel pontoons. These latter were rowed to the spot by special tugs. The length of the bridge was 350 m and its width 20 m. Ships were diverted through the navigation canal and the downstream lock.

On 22 October, 1955 heavy trucks, loaded with stone, started to arrive on the bridge and dump their stone onto the river bed. A decisive stage in the damming of the river was reached on 31 October, 1955. On that day the last of the stone was dumped. The velocity of flow had been reduced from 30 to 5 m/sec.

The next stage then started: suction dredges fed slurry for the hydraulic filling of the earth dam. As the dam increased in height, the water level in front of it rose, and the filling of the storage lake began. Filling was completed on 10 June, 1957. The part of the earth dam adjoining the Volga flood plain has a volume of 6.7 million m^3. It was filled in four months. After the damming of the Volga, the river-bed part of the dam was filled in two months (5 million m^3). In one period of 11 days during the filling of the river bed part of the dam, 2.6 million m^3 were handled. The maximum filling rate reached 300,000 m^3/day.

A feature of the construction of this plant was the continuity of the hydraulic filling: more than 20 million m^3 (20% of the total volume) were handled during the winter season. During the severe winter of 1955/56, with air temperatures dropping to -40° C, hydraulic filling did not stop, even for a second, and more than 7 million m^3 of fill were handled.

During the seven years of construction, the following work was performed: 193.9 million m^3 earthwork, including 107.8 million m^3 by hydromechanization; 7.67 million m^3 of concrete, including more than 3 million m^3 for the powerhouse, installation of 154,600 tons of steel structures, 397,000 tons of steel reinforcing, 370,000 tons of precast reinforced concrete, and 45,000 tons of steel piling. Eighteen million m^3 of rock, which figure includes 15 million m^3 of gravel from the carbonate deposits of the Zhiguli and Sok mountains, were delivered.

The remarkable achievements of the Soviet constructors can best be seen by comparing the Volga and Dnieper plants: the rate of concreting at the Dnieper site was only 5380 m^3/day compared with 19,050 m^3/day on the Volga site.

The world record for concreting, previously held by the constructors of the Grand Coulee Power Plant — 15,700 m^3/day — has been beaten by the USSR (Table 18).

The earth removed from the site of the Volga HEP would have been sufficient to make a wall 10 m high, 10 m thick, and over 1900 km long (the distance from Moscow to the health resort of Gagra!) [near Sochi].

Proper organization of the site and the construction of site workshops permitted a high degree of mechanization of excavation (98.4%), concrete mixing and pile driving (100%), and material handling (87.5%).

Concrete was mixed in stationary plants of batch-production type. These have a capacity of 18,000 m^3/day and a yearly output of 3,825,000 m^3.

The high degree of mechanization on the construction site is evident from the fact that, on some days during 1954, production equipment took more than 75 Mw, i.e., more than the installed capacity of Volkhovskaya HEP.

Thanks to this high degree of mechanization, earthwork reached a rate of 50 million m^3/year, and concrete placing 3,134,000 m^3/year.

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An important factor in hastening the commissioning of the plant was the combining of erection and assembly, using large prefabricated structural elements and blocks. Some comparative figures will make this clearer. Thus, in the construction of the American McNairy Hydroelectric Station, the installation and final assembly of the 14 turbine units took about three years (1953-1956); the installation and commissioning of the 20 units of the Volga HEP was carried out in only 20 months. It is interesting to note that the first two units were installed in 75 days, while the last six units required only 73 days. Thus, in just three months, the installed capacity of the plant went up by 630 Mw, more than the total power of the Dnieper HEP, where the installation of a single unit took 45 days, with an average interval of 34 days between the completion of work on one unit and the start of work on the next.

While the construction of the Volga HEP required 40,000 workers, the operating staff of the plant does not exceed 500 men.

The constructors of the plant increased their professional skill on the construction site, which was, in effect, a professional school. Many of the personnel were sent to other power-construction projects when they had finished their work at the Volga Plant.

An outstanding event in the progress of power construction was the commissioning of the Volga-Moscow 400 kv double-circuit transmission line. The line has a length of 1900 km and transmission capacity of 1 million kw. It was officially inaugurated in 1956. Two years later, a 500 Mw transmission line of still higher capacity, the Volga-Ural line, was put into operation. Apart from these two lines, the Volga HEP is connected through several 220 kv and 110 kv lines to the Kuibyshevskaya, Saratovskaya, and Ulyanovskaya power systems.

The construction of the Irkutskaya HEP (660 Mw), commissioned to full capacity in 1958, marked a new stage in the harnessing of the Angara River — a powerful tributary of the Siberian river, the Yenisei. The Irkutskaya HEP has no concrete spillway. Instead, the river bed is dammed by an earth dam, filled with locally available gravel; the dam has a clay core 41 m high. The powerhouse is incorporated in the spillway structure, and has special outlets for the discharge of excess water (see Figure 39).

The huge earth dam (volume 9 million m^3) was constructed using draglines. Damming and concrete placing were carried out, notwithstanding the low air temperatures (as low as -40° C).

The total volume of earthwork, including embankments, dikes, dams, inlet and outlet channels, etc., reached 35 million m^3. The powerhouse alone required more than 800,000 m^3 of reinforced concrete.

From the Irkutskaya HEP, the water passes to the construction site of the downstream Bratsk Plant — the next stage of the Angara-cascade scheme. In 1957 a 648 km high-voltage line linked the Irkutskaya Plant with the Bratsk site. The construction of the Bratskaya HEP involved more than 250,000 m^3 of earthwork. A passage had to be cut through the taiga forests 80 m wide and 400 km long, and 4000 tons of steel-cored aluminum conductor were strung.

The massive concrete gravity dam is 126 m high, 1450 m long, and has a volume of 5 million m^3 (see Figure 28).

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The construction figures achieved at this site are impressive: the project involved the construction of 400 km of railroads and highways, several large worker settlements, various workshops, etc. According to the schedule the amount of earthwork will reach 30 million m^3, excavation 6 million m^3, concrete placing 6 million m^3, and tree felling 38 million m^3. In 1958 the excavation pit was ready for concrete placing and the erection of the first structures was started.

The first turbine units of the plant were put into operation in October 1961.

Another important source of water is the Yenisei River, the harnessing of which is called for in the directives of the XX Party Congress (construction of Krasnoyarskaya HEP).

To sum up the period 1956-1960: the construction of all hydro developments required the following amounts of work: 730 million m^3 of earth and rock excavation, and 21 million m^3 of concrete placing. This is eight times the volume of work carried out during the first postwar plan (1946-1950).

NOTES

[1] Razvitie elektrifikatsii Sovetskoi Strany 1921-1925 (The Development of Electric-Power Generation in the Soviet Union during the Period 1921 to 1925), pp. 117-118, Moskva. 1956.

[2] Leninskii Sbornik (Collection of Lenin's Writings), Vol. XXIII, pp. 29-30.—(Note written on 2 September, 1921, on a letter by G.O. Graftio dated 26 August, 1921).—Moskva, Partizdat. 1933.

[3] Krzhizhanovskii, G. Elektroenergetika (Electric-Power Engineering), pp. 291-292, Moskva-Leningrad. 1933.

[4] Leningradskaya Pravda, 10 June 1924.

[5] It is now intended to replace the obsolete equipment at the Volkhov HEP with new turbines and generators, thus raising the output of the plant by 13%.

[6] Kuibyshev, V. Izbrannye proizvedeniya (Selected Works), p. 98 Moskva, 1958.

[7] V. pomoshch' politicheskomu samoobrazovaniyu, No. 4, p. 130. 1957.

[8] Krzhizhanovskii, G. Elektroenergetika (Electric-Power Engineering), p. 292, Moskva-Leningrad. 1933.

[9] Of the eight generators installed at this station, four were of Swedish origin and four from Leningrad. These were the first Soviet high-capacity generators. Their weight was 19.6% less than the weight of the similar Swedish generators which, incidentally, proved less reliable in operation than their Soviet counterparts.

[10] Petrogradskaya Pravda, 7 November 1923.

[11] KPSS v rezolyutsiyakh (Resolutions of the CPSU), Part II, p. 570.

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[12]Ibidem, p. 565.

[13]See Dnieprestroi (Dnieper HEP Construction Project), 1928, p. 190. During construction of the plant it transpired that the turbine-manufacturing plants could produce turbines of a much higher rating. A decision was adopted, therefore, to increase the power of the Dnieper HEP to 810,000 hp.

[14]In fact, by this date, five turbine sets were already operating routinely.

[15]Among the large American hydropower plants of that time, we should note the following: the Wilson Plant on the Tennessee River (430 Mw), and the plant on the Niagara (290 Mw).

[16]Nesteruk, F. Malyi ili bol'shoi shlyuz na Dneprostroe (Choice between Large and Small Locks for the Dnieper HEP).— Stroitel'naya Promyshlennost', No. 3, 1928; Ocheretyanyi, I. Rekonstruktsiya Dneprovskogo shlyuza (Reconstruction of the Dnieper Lock).— Rechnoi Transport, No. 11. 1961.

[17]Lenin, V.I. Sochineniya (Works), Vol. 35, p. 399.

[18]Nesteruk, F. Beton i betonnoe khozyaistvo gidrotekhnicheskikh sooruzhenii (Concrete and its Production and Placing in Hydrotechnical Structures), pp. 62-63, Moskva-Leningrad. 1941.

[19]Each kilowatt-hour produced at hydroelectric stations saves 0.7 to 0.8 kg of the fossil fuel burnt in thermal power stations.

[20]Lenin, V.I. Sochineniya (Works), Vol. 27, p. 288.

[21]Sekhniashvili, G. K istorii elektrifikatsii tyagi na Zakavkazskikh zh. d. (History of the Electrification of the Transcaucasian Railroads), Tbilisi, 1955.

[22]Documents of the Government Commission for the Acceptance Tests of the Nizhne-Svirskaya HEP, Vol. I.

[23]Sbornik: "Direktivy KPSS i Sovetskogo pravitel'stva "Collection: ("Directives of the CPSU and Soviet Government"). —Vol. 2, p. 393.

[24]Nesteruk, F. Vodnoe stroilet'stvo Moskvy (Hydrotechnical Structures of Moscow), 1950; Rumyantsev, A. Moskva-Leningrad. Opyt ekspluatatsii kanala imeni Moskvy (Experience in the Operation of the Volga-Moskva Canal).— In: Sbornik "Ekspluatatsyia gidrotekhnicheskikh sooruzhenii", Rechnoi Transport, p. 38, Moskva. 1955.

[25] Direktivy KPSS i Sovetskogo pravetel'stva (Directives of the CPSU and the Soviet Government), Vol. 2, p. 573.

[26]Nesteruk, F. Zakoncheno napolnenie velichaishego iskusstvennogo vodokhranilishcha (A Huge Storage Lake has been Completed).— Elektricheskie Stantsii, No. 4. 1943.

[27]Zhurin, et al. V.D. Sbornye zhelezobetonnye obolochki gidrotekhnicheskikh sooruzhenii (Precast Reinforced-Concrete Shells for Hydrotechnical Structures).— Gidrotekhnicheskoe Stroitel'stvo, No. 1, 2. 1952.

[28]The increasing share of hydroelectric stations in the total power generation is of utmost economic importance: each million kw of hydropower gives an annual economy of hundreds of thousands of tons of fuel.

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[29]Direktivy KPSS i Sovetskogo pravitel'stva (Directives of the CPSU and the Soviet Government), Vol. 2, pp. 709-710.

[30]The Farkhad HEP was completed after the war. In 1948 the last set was commissioned and this satisfactorily established the generating capacity of Tashkent power system. This permitted the irrigation of 150,000 hectares of arid land in the famous Golodnaya Steppe. After the war, foreign equipment at the plant was replaced with up-to-date Francis turbines, manufactured by the Leningrad Metal Works. The last of the turbines for this plant was delivered in 1959.

[31]The Rybinskaya HEP has since been interconnected with the Central Power System, and is linked to Moscow by a 220 kv line.

[32]It is interesting to note that, in the reconstruction work, the Leningrad Metal Works, the manufacturers of the turbines used welded stainless-steel blades, weighing up to ten tons, this being the first time this technique had been used anywhere.

[33]The completely reconstructed Volkhov HEP (1944) had an installed capacity of 64 Mw, i.e., 14% more than its prewar capacity; today, the annual saving of fuel which would have to be hauled long distances, is 20,000 tons.

[34]"Zakon o pyatiletnem plane vosstanovleniya i razvitiya narodnogo khozyaistva SSSR na 1946-1950 (The Law of the Five-Year Plan for the Reconstruction and Development of the National Economy of the USSR, 1946-1950).— Gospolitizdat, p. 8. 1946.

[35]Ob itogakh vypolneniya chetvertogo (pervogo poslevoennogo) pyatiletnego plana SSSR na 1946-1950 (Figures on the Implementation of the Fourth (Postwar) Five-Year Plan of the USSR, 1946-1950).— Gospolitizdat, pp. 6-7. 1951.

[36]The underground powerhouse of the recently completed Canadian Nechako-Kemano HEP required excavation 25×213×41 m, a total volume of 2 million m^3.

[37]Direktivy KPSS i Sovetskogo pravitel'stva (Directives of the CPSU and of the Soviet Government), Vol. 3, p. 22.

[38][Original text presented as table; data of original footnote now superfluous.]

[39]Pravda, 28 December, 1950.

[40]One of the largest dams in the world (L = 25 km) is at present the Khirakud Dam in India (cf. F. Nesteruk, Vodnye resursy Indii i ikh ispol'zovanie (India's Water Resources and their Utilization), in 1960).

[41]52% of the work was carried out in 1951. The total volume of earthmoving and auxiliary work (excluding quarrying) was 194.3 million m^3.

[42]Experience in the operation of this development revealed certain disadvantages resulting from the common location of the powerhouse and locks in a single structure, located below the assembly bay in front of the water-outlet lock gates (sluices).

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[43]Direktivy KPSS i Sovetskogo pravitel'stva (Directives of the CPSU and the Soviet Government), Vol. 3, p. 672.

[44]An increase in the utilization of the installed capacity from 1000 hours to 3000 hr/year reduces the prime cost of electricity by almost half.

[45]Direktivy XX s"ezda KPSS po shestomu pyatiletnemu planu razvitiya narodnogo khozyaistva na 1956-1960 (Directives of the XX Party Congress for the Sixth Five-Year Plan of Development of the National Economy).— Gospolitizdat. 1956.

[46]In 1957 the operating staff of the plant discovered an important fact: after spring high water, when the storage lake was filled to capacity and the head on the turbine reached its maximum value, the turbines developed 125 Mw instead of the manufacturer's guaranteed minimum of 105 Mw. Investigations confirmed the possibility of operating at the increased capacity for long periods. These investigations permitted the revision of the rated capacity of the units and a rating of 126 Mw was established. In October 1957 the power plant reached its rated capacity.

[47]A feature of the Tereblya-Rikskaya HEP is the use of two parallel rivers — the Tereblya and the Rika (the Tereblya being 200 m above the level of the Rika) — to supply a single tunnel 4 km long. This tunnel lies at considerable depth.

[48]In October 1961 excavation on the longest section of the diversion tunnel for the No. 2 plant was finished. The tunnel has a length of 7 km and an internal diameter of 4 m. A single excavation gallery, 4.5 km long, was driven from one end of the tunnel. This is the longest single-excavation stretch ever driven in Soviet practice. In the construction of this project the space between the penstock liners and the rock was filled by the method of separate concreting. This was the first time this had been done in the USSR.

[49]Kairak-kum in the Tadzhik language means "abrasive sand".

[50]Khrushchev, N.S. Rech' na mitinge stroitelei volzhskoi gidroelektrostantsii, im. I.V. Lenina 10 Avgusta 1958 (Speech Delivered by Khrushchev to a Meeting of the Constructors of the Volga HEP im. Lenin, on 10 August, 1958), p. 18.

[51]Ibid.

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Chapter IV

POWER CONSTRUCTION DURING THE PERIOD OF THE SEVEN-YEAR DEVELOPMENT PLAN OF THE SOVIET NATIONAL ECONOMY (1959-1965)

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The target figures of the new Seven-Year Plan provide for an ever-increasing rate of power construction, which should outstrip the rate of general industrial construction. During this period annual power generation should reach 500 to 520 billion kwhr (see Table 19). Compared with the figures for 1958, this would mean an increment of 110 to 120%; the growth of general industrial production is 80%, and of the means of production 85 to 88%. At the same time, the installed capacity of hydropower plants should increase by 58 to 60 million kw, thus exceeding the capacity of all hydropower plants ever built in the USSR. In other words, the target figures for the current Seven-Year Plan are more ambitious than they have been in all the 41 years since the establishment of the Soviet regime. This impressive goal requires the yearly commissioning of 8.5 million kw and, toward the end of the plan period, 11 million kw.

TABLE 19

Power construction covered by the Seven-Year Plan (target figures approved by the XXI Party Congress)

Item	1958	1965
Total generation, billion kwhr	223.4	500 – 520 (540)
hydropower included, billion kwhr	46.4	100
%	20	18
Total installed capacity, million kw	53.4	111 – 113 (121)
hydropower included, million kw	10.8	21 (28)
%	20	23
Planned increment in installed capacity, million kw	–	58 – 60 (68)
hydropower included, million kw	–	10 – 11 (18)
Hours of annual utilization	4717	4500
Length of 35-500 kv transmission lines, thousand km	100	311
500 kv lines included, thousand km	–	10.7
Power equipment, million kw		
turbines of various types	6.6	18.7 – 20.4
generators	5.2	17.5 – 18.4

Note: Installed capacities and outputs after planned expansion are given in brackets (see p. 114).

A primary condition for comprehensive electrification is an increase in the length of transmission lines. The Seven-Year Plan envisages an increase in transmission-line voltages from 500 kv a-c to 800 kv d-c. Total line length is to be 200,000 km, i.e., three times more than in 1958 (see Figure 30). The specific length of transmission lines is to be increased

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to 33 km per 100 km² of inhabited area, i.e., four times the 1958 level. The new plan, like the previous ones, provides for further concentrating of installed capacity in large power plants, and for the expansion of power systems.

The new plan lays particular stress on the construction of thermal power plants using natural gas, crude oil, and cheap coal. This is because the construction of thermal plants requires less time, investment, and labor than hydropower plants with their multiple hydrotechnical structures (dams, channel, locks, etc.). The plan provides for a 50 million kw increase in installed thermal capacity.

This does not mean, however, that the construction of new hydropower plants will be neglected. The Seven-Year Plan calls for the installed capacity of existing hydroelectric plants to be increased from 7.4 million kw to 11 million kw[1]. The new plants are to be highly efficient and economical, i.e., minimum capital investment per unit installed capacity. This refers particularly to the hydroelectric plants to be erected on the Angara, Yenisei, and other Siberian rivers.

As was brought out at the XXI Party Congress, the construction of some hydropower plants will be slightly delayed. However, once some of the most urgent problems of industrial development are solved by the putting up of thermal plants, the constructors will again pass to the harnessing of hydropower resources[2].

The new plan lays particular stress on the construction of high-head plants in Siberia, the Caucasus, and the Far-East Region, and in Soviet Central Asia.

The share of hydropower in the total power generated remains unchanged at the present-day level (Figure 71). Toward the end of the period 1959-1965 some of the largest hydroelectric plants will have to be commissioned to their full capacity. Among them are the Volga HEP im. XXII Party Congress (2530 Mw), Bratskaya HEP on the Angara (4500 Mw), Votkinskaya HEP on the Kama (1 million kw), Kremenchugskaya HEP on the Dnieper (625 Mw), Bukhtarminskaya HEP on the Irtysh (675 Mw), Novosibirskaya HEP on the Ob (400 Mw), and Saratovskaya HEP on the Volga (1 million kw). Other work will be carried out on the multipurpose utilization of the Volga, Kama, and Dnieper rivers for power generation and navigation. The end of the Seven-Year Plan will witness the completion of the largest hydroelectric plant in the world — the Krasnoyarskaya HEP on the Yenisei, with an installed capacity of about 6 million kw.

Important changes are envisaged in the geographical distribution of hydropower plants. Most of the new plants are to be erected in Siberia, this province being the richest in water resources. Here, the total installed capacity will increase six times, and the share of hydropower plants in the total power generated will reach 37%.

The construction of the giant Bratskaya HEP (4.5 million kw) in the severe conditions of the Angara taiga is progressing at an ever-increasing pace. The construction of this plant, which is twice as large as the largest American plant on the Grand Coulee Dam, has been described by Averell Harriman as an outstanding achievement of Soviet power construction. During the winter of 1960/1961, the main concrete-transporting trestle and the concrete river dam linked the two banks of the river. The first four turbine units of the plant were put into operation in 1961, and the other six at the end of 1962.

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For another giant, Krasnoyarskaya HEP, the designers at the Leningrad Metal Works and the Elektrosila Plant decided to construct compact turbine sets with a unit capacity of 500 Mw (Figure 67). The design of the turbines made it possible to install twelve units in a somewhat small powerhouse, the relatively small site being constricted by the left-bank cofferdam. Cofferdams 15 m high were built on the left-bank site. The width of the cofferdams is 20 m. The filling of the storage reservoir will start in 1965.

The share of hydropower in the total power supply of the Central and Volga regions, already high in 1958 (32%), will increase by 1965 to 34%.

The first turbine unit of the (for the time being) largest hydropower plant — the Volga HEP im. XXII Party Congress — was commissioned in December 1958. The last of the 21 units[3] was put into operation on 9 December, 1960, a year ahead of schedule. The plant was erected near the heroic town of Volgograd (Figure 25).

With an installed capacity of 2563 Mw the plant is capable of generating 11 billion kwhr yearly. The plant will be linked to the Unified Power System of the European part of the USSR by 220 and 500 kv lines. The plant is also connected to Donbass by a ± 400 kv d-c line (Figure 70).

The Saratovskaya HEP (1 million kw) is to be commissioned during the current Seven-Year Plan[4]. The intention is that this plant should serve as an example in the use of advanced industrial and constructional techniques. The design makes considerable use of precast concrete blocks; complete mechanization of concrete placing, and the handling of formwork, reinforcing steel, etc., is envisaged.

The current Seven-Year Plan lays particular stress on the importance of building the Cheboksarskaya and Nizhne-Kamskaya hydropower plants. These stations will have a total installed capacity of 2.5 million kw. They are intended to furnish the central industrial regions and the Ural Area with 6.4 billion kwhr of cheap electricity per year.

The construction of these plants is also necessary for other reasons. Their storage lakes will equalize the depth of the Volga and Kama rivers, thus improving navigation. At present, the somewhat shallow depth of these rivers is increased for navigation purposes by drawdown from the Rybinsk, Gorki, and Perm storage lakes, which reduces their power-generation potential.

In December 1961, the Ural power system acquired additional generating capacity with the commissioning of the first two turbine units of the Votkinskaya HEP (1 million kw). This plant, with the powerful Volga HEP (which has a guaranteed power of 900 Mw), Perm, Pavlovskaya HEP on the Ufa River (160 Mw), and a series of smaller hydropower plants, will together furnish sufficient electricity to meet the increasing power demands which will arise during the current plan period.

The power of the Ural system will be raised after the completion of the Krasnoyarskaya HEP with its 6 million kw and 35 billion kwhr per year.

An acute problem has to be solved — the regulation of the flow of the Kama River. After completion of the Votkinskaya HEP, the stretch of the Volga downstream from the Votkinsk Dam up to the storage reservoir of the Volga HEP will have insufficient depth for trouble-free navigation. This problem will probably be solved by the construction of the 1.4 million kw, Nizhne-Kamskaya HEP (see Figure 31).

In the northern regions of the European part of the USSR (Murmansk and Karelia), the power construction envisaged by the current Seven-Year

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Plan is more than 85% hydropower. Already operating here are the Ondskaya HEP (80 Mw) and the Vygostrovskaya Plant (40,000 kw) which, together with the Matkozhnensk Plant, will form a cascade of hydropower plants along the White Sea-Baltic Sea Canal. Another cascade on the Suna River will be formed by the Palesandal'skaya HEP and the Kondopozhskaya HEP. The Kumskaya HEP on the Kuma River is near completion, and the construction of the Novskaya HEP is to be started shortly. As a result of this new capacity, power supply to Karelia will be doubled.

The Seven-Year Plan in the Baltic Soviet republics provides for the construction of three hydropower plants: Kaunasskaya (completed in 1960), Sovetskaya HEP on the Neman River in Lithuania, and Plyavin'skaya HEP on the Western Dvina in Latvia (825 Mw).

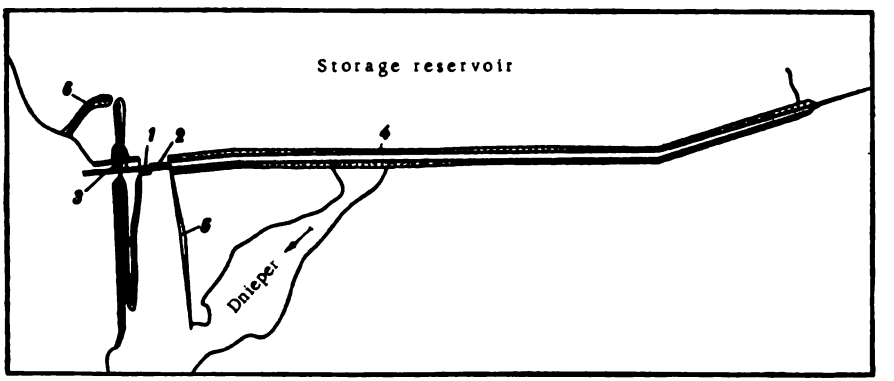

FIGURE 24. Layout of the Kremenchugskaya HEP

1 — powerhouse; 2 — concrete dam; 3 — lock; 4 — earth dam; 5 — tailwater channel; 6 — dike-breakwater

In the Ukraine good progress is being made with the harnessing of the Dnieper River. The new plan provides for the construction of two plants of the Dnieper cascade system — Kremenchugskaya HEP (commissioned in 1960) and the Dneprodzerzhinskaya Plant. However, the regulation scheme for the Dnieper flow will only be completed after the construction of two other plants — the Kievskaya and the Kanevskaya plants. (These two stations are already under construction.)

The Kremenchugskaya HEP, which has an outdoor powerhouse and the largest runoff-regulation storage lake in the Ukraine, was officially inaugurated on 31 October, 1960, two years ahead of schedule[5].

The Kremenchug hydro development (Figure 24) comprises a powerhouse, concrete spillway dam, navigation lock, and an earthfill dam. All the concrete structures are erected on granite on the right-hand arm of the river, and in its flood plain. An earthfill dam on sandy foundation crosses the island between the right-hand arm and the main river as well as the river bed itself and the left-hand flood plain.

The construction of the plant involved about 73 million m^3 of earthwork, 4 million m^3 of rock excavation, the placing of 1 million m^3 of concrete,

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and the installation of 60,000 tons of steel structures and power and auxiliary equipment. The storage lake required 12 million m^3 of earthwork and 40,000 m^3 of concrete placing.

As in other projects, the designers and constructors of the Kremenchugskaya Plant faced a series of engineering problems, many of which were solved in a novel manner: the powerhouse is the first in the USSR of the outdoor type; wide use was made of large facing blocks (weighing up to 4.5 tons and precast reinforced concrete elements; another novel feature was the construction of the earth dam, without the use of steel-sheet piling. All these innovations saved more than 16,000 tons of steel.

Despite the complicated geological conditions of the site (the lock was constructed in a rock excavation with a depth varying from 8 to 21 m), concrete work was completed in only 18 months, 9 months less than at the Kakhovskaya HEP. Much of the earthwork has been carried out by hydromechanization. Twelve turbine units were installed in 11 months (Figure 37), using special high-productivity methods.

During the period of the Seven-Year Plan, hydro developments will be built in Georgia: the Ladzhanurskaya, Khramskaya No. 2, Tkibulskaya, and Gumatskaya plants. Construction will be started on the Daryal'skaya Plant on the Terek River and the new Rionskaya Plant on the Rion River. Work is under way on the completion of the first stage of the Inguri cascade system, comprising an arch dam of 299 m in height (the highest in the world), a 19 km long water-supply tunnel, and an underground powerhouse. The installed capacity of the plant will be 1.4 million kw. Other features are: a concrete dam with a volume of 2.9 million m^3; underground excavation work of 2.6 million m^3; and 490,000 m^3 of underground concreting.

The Seven-Year Plan envisages the interconnection of the networks of Georgia, Armenia, and Azerbaidzhan to form a single power system; the Mingechaurskaya HEP will be linked to Georgia by a 220 kv line, which will ultimately be connected to the Armenian power system.

Particular account is taken of Kazakhstan in the current Seven-Year Plan: toward the end of the period of the plan, i.e., in 1965, power generation is to increase by a factor of 3.54 compared to 1958. This will have a strong influence on the industrial development of the republic (ferrous and nonferrous metalworking, coal- and metallic-ore mining industry). During the period 1959-1965, Kazakhstan's hydropower plants will furnish an additional 700 Mw. Of this, 525 Mw will be supplied by the Bukhtarminskaya hydro development on the Irtysh. This project comprises: a run-of-river plant; a concrete spillway dam 90 m high; nonoverflow dams adjoining the river banks; and a four-chamber navigation lock. The rated capacity of the plant is 675 Mw (provided by nine turbine units)[6]. The filling of the storage lake started in April 1961. By October of the same year the level of the lake rose by 61 m, the volume stored being 25 billion m^3. The area of the lake is 3000 km^2.

The construction of the plant involved the following work: 4.8 million m^3 of earth and rock excavation, 1.2 million m^3 of concrete (including 100,000 m^3 of precast concrete, and the erection of 11,000 tons of steel structures.

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The production of stiff concrete, previously used only seldom in power construction, was mastered. Massive blocks of up to 8000 m^3 were made from this material. This permitted a reduction of 80,000 tons in the quantities of concrete allowed for in the design.

In general, during the first stage of the development of their water-power resources, the republics of Soviet Central Asia laid particular stress on irrigation (see Figure 48). Each new Five-Year plan led to new successes in power production and utilization. The share of hydropower in the total power production of the area will probably exceed 50 %.

In Tadzhikistan, the construction of the Perepadnaya HEP (30 Mw) on the Vakhsh River was completed in 1958; the Golovnaya HEP (210 Mw) is nearing completion, and the Tsentral'naya HEP is now (1963) under construction. The setting up of Nurekskaya HEP (installed capacity 2700 Mw, output 11.8 billion kwhr/year) — the largest stage of the Vaksh River cascade system — was started in 1961.

The following plants are being erected in Kirghizia: Uch-Kurganskaya (112 Mw) on the Naryn River, Shaarikhanskaya on the Shaarikhan-Sai irrigation canal, and two plants on the Chu Canal. The first turbine unit of the Uch-Kurganskaya HEP was commissioned in November 1961. For this plant 4 million m^3 of earth and rock had to be excavated, 260,000 m^3 of concrete placed, and 3000 tons of steel structures erected. The plant was put into operation with full rated capacity in November 1962.

Uzbekistan power needs were, and still are, met mainly by hydroelectric stations. Tens of hydropower plants have been erected during the Soviet regime. In 1958, the hydropower plants of Tashkent power system produced more than 70 % of the total output. However, after huge deposits of natural gas were discovered in the area, it was decided to expand the construction of thermal power plants. Hydropower plants will be erected in connection with storage lakes and irrigation systems.

In accordance with the Seven-Year Plan, studies are being conducted on the utilization of the waters of the Lena River Basin in the Yakut SSR (Northern Siberia) for the production of cheap power for the diamond mines (see Figure 42). The conditions in this area — difficult climate, permafrost soil, and large distances for transmission lines — make power construction difficult.

The first experimental hydropower construction in permafrost soil started in 1957 near the town of Bodaibo, where a concrete dam has been erected on the Mamakan River, a tributary of the Vitim River. The work involved the placing of 365,000 m^3 of plain and reinforced concrete, the construction of 30,000 m^2 of dwellings (floor area), and 140,000 m^2 (floor space) of various temporary shops and other industrial facilities. The first two hydropower units of the new plant were put into operation at the end of December 1961, and the plant was fully commissioned at the end of 1962.

Another large hydropower plant in this area is the one on the Vilyui River. Construction started in 1961. The Vilyui development comprises a rock-fill dam 67 m high, with a volume of 2.3 million m^3; and a powerhouse of semi-underground type, lined with concrete slabs.

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Since the frozen soil in this area thaws partially during the summer, a special heat-insulating cover had to be provided for the construction site, and access roads had to be constructed. To carry the water discharge during the construction period, a tunnel with over-all dimensions of 17.5×14× ×260 m had to be constructed on the rocky left-hand bank of the Vilyui River. More than 64,000 m^3 of concrete will have to be placed for the first stage of the plant which will be completed toward the end of the current Seven-Year Plan period.

Soviet power constructors made special efforts to achieve the targets ahead of schedule. Thus, more than 1.75 million kw were installed in 1959, and more than 2 million in 1960, exceeding the requirements of the plan by 20%. More than 1.4 million kw were installed in 1961; 3 million kw were installed in 1962.

In line with the directives of the communist party[7], the following hydroelectric plants were commissioned during the first half of the Seven-Year Plan: Kremenchugskaya HEP on the Dnieper, Kaunasskaya on the Neman, the Atarbekyanskaya and Erevanskaya plants of the Seven-Razdan cascade-system in Armenia, the Ladzhanurskaya and Sharoi plants in Georgia, Perepadnaya in Tadzhikistan, Ust'—Kamenogorskaya HEP on the Irtysh River, Pavlovskaya HEP on the Ufa River in Bashkiria, and the giant HEP—the Volga Plant im. XXII Party Congress on the Volga.

In view of the fact that the target figures were exceeded during the first years of the current plan, a decision was adopted to increase the target figures to 68 million kw of installed capacity, and an output of 540 billion kwhr, this level to be achieved toward the end of 1965. It was regarded as feasible to increase the share of hydropower in these figures from 10-11 to 18 million kw. This took into account the 14 million kw installed in the period 1961-1965.

Great successes were obtained in 1961 in the field of power construction. The Bukhtarminskaya HEP on the Irtysh, the Iovskaya HEP on the Kovda (Murmansk Region), and the Vygostrovskaya HEP on the White Sea-Baltic Sea Canal were completed; the first four 225 Mw turbine units of the Bratskaya HEP were put into operation, as were the first two 100 Mw units of the Votkinskaya HEP on the Kama, the first units of the Chir-Yurtskaya HEP on the Sulak River (Dagestan), and the first 45 Mw unit of the Uch-Kurganskaya HEP on the Naryn River (Kirghizia). More than 1.4 million kw of new capacity was installed during 1961.

During the year work continued on the construction of Krasnoyarskaya[8], Saratovskaya, Dneprodzerzhinskaya, Kievskaya, Verkhne-Tulomskaya, Vilyuiskaya (see above), Golovnaya on the Vakhsh River, Kumskaya on the Kuma River, Borisoglbeskaya and Plyavin'skaya on the Western Dvina River in Latvia, Nurekskaya in Tadzhikistan, and many other hydroelectric plants. It was intended to put into operation eight units at Bratskaya HEP, 5 units at Votkinskaya HEP, 3 units at the Bukhtarma Plant, 2 units of the Uch-Kurganskaya Plant, as well as many other turbine units at Vologhaya, Dneprodzerzhinskaya, Kievskaya, Yerevanskaya, Khramskaya No. 2, and some other stations. Thus in 1962, it was intended to install about 3 million kw of new hydropower capacity.

Work is also in progress on the design of several large hydroelectric plants: Sayanskaya HEP on the Yenisei[9], Ust'-Ilimskaya on the Angara,

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Ingurskaya on the Inguri River in Georgia[10], Cheboksarskaya and Nizhne-Volzhskaya (Astrakhan') on the Volga, Nizhne-Kamskaya HEP on the Kama, Chirkeiskaya on the Sulak River in Dagestan SSR, Shul'binskaya on the Irtysh, Mogilev-Podol'skaya on the Dniester, Kanevskaya on the Dnieper, Kapchagaiskaya on the Ili (Kazakhstan), Zeiskaya on the Zeya River (a tributary of the Amur), Sovetskaya on the Neman River in Lithuania, Tatevskaya on the Vorotan River in Armenia, etc.

In July 1961, the Ministry for the Construction of Power Plants of the USSR approved the construction plans for the Kislogibskaya experimental tidal-power plant which will be completed in 1964[11].

A feature of current trends in power engineering is the gradual interconnection of the various power networks to form a national power system for the whole of the USSR. The backbone of the national system — the European USSR unified power system — will supply more than 50% of the country's power needs. The power network of Central Siberia, which has an installed capacity of about 15 million kw, will be connected to the national power system.

The creation of the national power system will be made possible by the construction of 330 and 500 kv lines. Lines operating at 500 kv are being increasingly used for the transmission of power over great distances in Siberia, Kazakhstan, etc. The plan envisages the erection of 11,000 km of 500 kv lines and 7000 km of 330 kv lines (see Figure 70).

On 27 December, 1959 — a noteworthy date in the development of Soviet and world power engineering — the section of the eastern circuit of the 500 kv Volga-Moscow line up to the Southern substation, was commissioned. Until recently, 400 kv was the maximum transmission line voltage in most of the Western countries.

Another important event in 1960 was the commissioning of the d-c transmission line linking the Volga HEP im. XXII Party Congress with Donbass. The capacity of this line is 750 Mw. Current is transmitted at a voltage of 800 kv (± 400 kw to ground) over a two-wire overhead line, the line length being 470 km. The construction of this unique line completes the unified European USSR power system.

Other similar power systems will be set up in Azerbaidzhan, Kazakhstan, Central Asia, etc. These systems are based on the rich water resources of these regions and on the natural-gas deposits of Azerbaidzhan.

The growth of power construction has been accompanied by a radical improvement in equipment and structures.

The main task of power construction is now to reduce investment rates and construction times. The basic ways to achieve this were outlined at the All-Union Conference on Power Construction held in November 1959.

At the XXI Party Congress, representatives of power constructors undertook to construct additional plants representing 2 million kw without any additional investment: the construction would be financed by effecting savings in established programs. More than 50 projects were revised in the light of this commitment. It was established that a considerable reduction in costs could be made by introducing more advanced engineering techniques and by improving construction methods and equipment.

These are only the first steps in the national campaign for economy and the rapid fulfillment of the targets. Investigations continue in various directions. The main trend is the large-scale use of prefabricated concrete

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structures and flow-line assembly and installation methods, the final aim being to reduce the building of power plants to the erection of prefabricated and preassembled elements.

In line with these trends many new techniques, that reduce construction time and improve quality, have been introduced into Soviet power-engineering practice. Mention must be made of the improved layout of the pier-type powerhouses built at the Kama, Pavlovsk, Kakhovka, and many other hydro plants; the large-scale use of locally available construction materials for dams, and new methods of dam construction.

Despite these remarkable successes of Soviet hydropower engineering, many problems still had to be solved, particularly those concerning reduction of capital cost and construction time. These shortcomings in hydropower construction are all the more significant in the light of the success obtained in thermal-power construction, where capital costs have been drastically cut by proper planning, the introduction of large units, etc.

Ways of overcoming these shortcomings were given at one of the plenary sessions of the CPSU: the introduction of new, up-to-date equipment, mechanization of construction, and large-scale automation.

In line with these recommendations, hydropower construction is introducing new methods: economical equipment layout, mechanization of construction work, introduction of new construction methods, etc. The new designs make increasing use of precast concrete and preassembled concrete structures, which are now also being used in power plants with horizontal-shaft turbine units. A decisive stage in these new trends is the construction of the Kievskaya and Saratovskaya HEPs, where ample research work is being conducted.

Many new designs constitute a radical departure from conventional techniques.

Thus, prestressed-concrete structural elements, weighing up to 62 tons, are used on a large scale in the construction of the Kremenchugskaya HEP. These are employed in erecting massive structures for bridge spans, etc. Considerable savings of steel, labor, and time are achieved.

Preassembled prestressed-concrete structures are used in locks, penstock- and pressure-tunnel linings, channels, and upstream facings for dams.

Methods are being developed for the construction of dams and power complexes without using cofferdams. Large structural blocks for the power plant are brought to the site on floating bridges and pontoons.

Remarkable successes have been obtained in the installation of power equipment, delivered as large blocks of machinery. Thanks to such methods nine turbine units of 115 Mw unit power were installed in 1960 at the Volga HEP im. XXII Congress of the CPSU, and nine units of 52 Mw were put in at Kremenchugskaya HEP.

Important problems were also solved in electric-power industry. Soviet turbine units frequently have better characteristics than similar foreign equipment. Thus, the Volga plants were equipped with unique turbines with runners of 9.3 m diameter, while the runners for the turbines for Saratovskaya HEP are even larger — 10 m.

The four Francis turbines initially specified for the Chir-Yurtskaya HEP on the Sulak River in Dagestan, were replaced with two Kaplan turbines for a head of 43 m. The capacity of the plant was thus increased from 48 to 70 Mw, without any additional cost.

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Plans are under way to manufacture still larger hydraulic turbines of 200 to 300 Mw or more. The Bratskaya HEP has 225 Mw units, while the plans for the Krasnoyarskaya HEP specify 500 Mw units. These units make it possible to increase the installed capacity of the plant now under construction to 5 million kw (from 3.2 million kw), without additional cost.

The total volume of work covered by the current Seven-Year Plan amounts to 800 million m^3 of earthwork, 30 million m^3 of concrete placing, and the erection of 440,000 tons of steel structures.

The level of mechanization reached in 1958 is shown by the following figures: in earthwork — 97.5%; in concrete placing — 95.5%; and in the assembly of steel structures — 96.3%.

Another important trend in power construction is the widening scope of automation. While there are now in the USSR many fully automated hydropower plants, some even with remote control, construction work still lags behind in this field, except for a few notable examples (automatic concrete-mixing plants, automatic units for water-table lowering, and suction dredges).

Work done so far to speed up power construction is yielding results: many projects were commissioned ahead of schedule, and experience indicates that, in terms of reduced material consumption and shorter construction time, improvements can be made on design figures.

LARGE HYDROPOWER DEVELOPMENTS

The Volga HEP im. XXII Congress of the CPSU

A notable achievement of Soviet hydropower construction was obtained at the end of 1960: the commissioning of another Volga giant — the Volga HEP im. XXII Congress of the CPSU (Figure 25). At the time of writing this is the world's largest power plant (2530 Mw, excluding the power equipment for the fish lift [see earlier in this text])[12]. This plant will, in time, be surpassed by the Krasnoyarskaya HEP on the Yenisei. The new Volga Plant now under construction, outstripping such powerful American stations as Grand Coulee, Boulder Dam, and the huge power project on the Niagara (2190 Mw) exceeds its sister plant, the Volga HEP im. Lenin, by 263 Mw.

The annual output of the new plant, 11.1 billion kwhr, is six times the total output of all power plants in Tsarist Russia.

Hydropower plants have been successfully built on loose and pervious soils. The spillway dam of the Volgogradskaya HEP (Figure 26), with a height of 43 m and a length of 725 m, has the largest water discharge of all plants erected on sandy soil — 44 m^3/sec at the dam toe. A feature of this dam is the sluiceway, which is of monolithic reinforced concrete.

The powerhouse is combined with the sluiceway structures, which have a total water discharge of 15,000 m^3/sec. This type of construction made it possible to reduce the length of the spillway dam to a third of its length as originally designed, and thus to save tens of thousands of tons of reinforcing steel, concrete, etc. The powerhouse is much larger than the powerhouse of the first Volga Plant. The height from the base to the roof of the powerhouse is 75 m.

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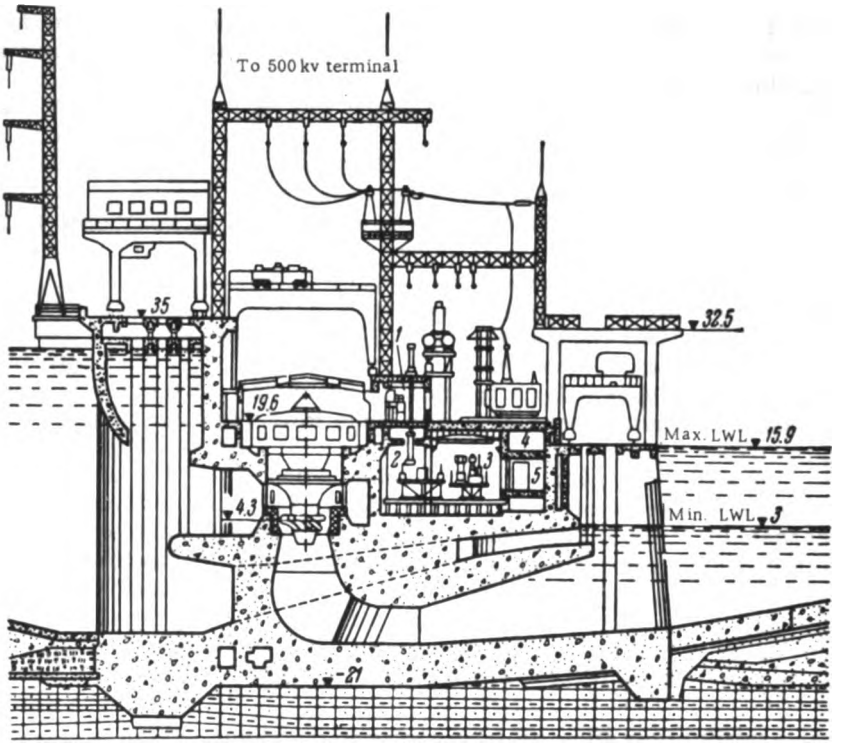

FIGURE 25. Cross section through the Volga HEP im. XXII Congress of the CPSU, showing location of the power equipment.

The Kaplan turbines installed at the new Volga Plant are, like those at its sister plant, of unprecedented size and power. They operate with a head that varies considerably from a minimum of 15.3 m to a maximum of 27 m. The maximum discharge capacity of all turbines is 15,700 m^3/sec.

The slightly lower head at the Volga HEP im. XXII Congress of the CPSU (compared with its sister station) and the reduced weight of the generator rotor gave a reduction in the total load on the thrust bearing from 3250 to 2900 tons.

The adoption of an electronic-excitation system in the new plant made the installation of generator excitation sets unnecessary, giving a reduced over-all height of the unit. As a result of such design improvements, the weight of the turbines installed at the Volga HEP im. XXII Congress of the CPSU does not exceed 1420 tons against 1650 tons at the first Volga Plant. The height of each unit is 40 m.

Control of the power equipment is carried out from a central dispatcher station in Moscow.

The hydro development, apart from the main hydrotechnical structures, contains a switchyard for 220 kv and 500 kv and a d-c conversion station. Two HV overhead lines from the 220 kv switchyard connect the plant to that part of the local power system situated on the right-hand river bank (a third line is at the design stage). Another two lines connect the part of the local system on the left-hand bank. The 500 kv line from the switchyard connects

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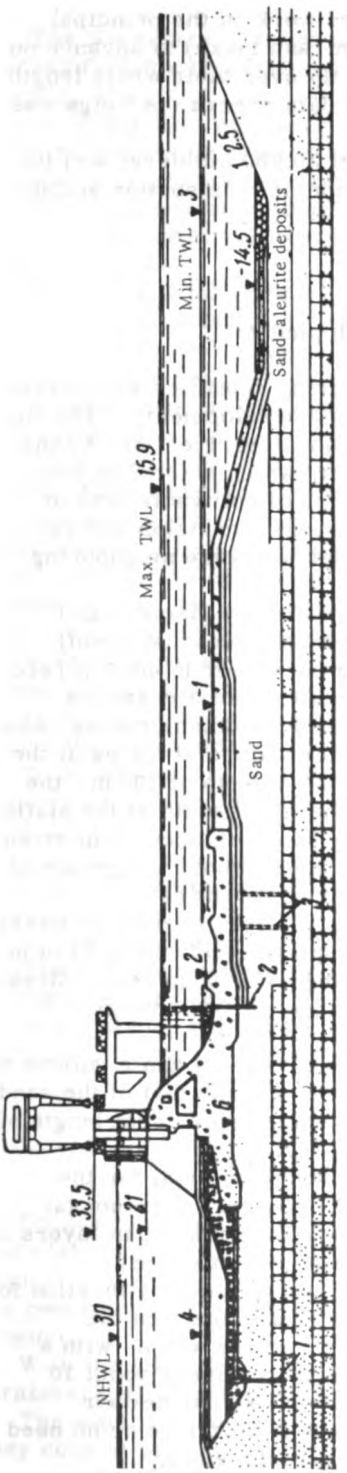

FIGURE 26. The spillway dam of the Volgogradskaya HEP

1 — steel-sheet piling; 2 — perforated-sheet piling; 3 — drainage wells

the plant with Moscow. The d-c line connects the plant with Donbass. The route of this line is along the right-hand bank.

The large size of the power plant and the complicated geological conditions on the site determined the volume of construction work: 144.3 million m^3 of earthwork for the basic structures (including 70% by hydraulic filling), 5.47 million m^3 of concrete, 2.1 million m^3 of drainage and filters, 1.4 million m^3 of stone embankments and facing, 25,000 tons of steel-sheet piling, 79,400 tons of steel structures, and 218,000 tons of steel reinforcing for concrete.

Although both Volga plants were constructed under almost identical geological conditions, the volume of civil-engineering work involved in the second Volga Plant was much smaller than at the first plant.

The directives of the XXI Congress of the CPSU laid particular stress on the continuous expansion of mechanization in power construction[13].

These directives were rigorously followed by the builders of the Volgogradskaya HEP. Most of the earthwork, water-table lowering, concrete placing, erection of steel structures, etc., was done by a flow-line method, with broad use of mechanization. Toward the end of 1958, there were available on site 19,000 units of various types of construction equipment: 100 excavators, 50 bulldozers, scrapers, tractors, pipe layers, and 1950 trucks, etc., representing a total electric load of 427,227 kw.

The powerhouse, the spillway dam, and the ship locks were located on the river flood plain. Earthfill dams were erected on the Volga in the remaining part of the flood plain. This permitted part of the Volga channel to be kept free for streamflow and navigation.

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This procedure (using solid cofferdams) allowed work on the principal concrete structures (powerhouse, spillway dam, and locks) to advance on the dry site behind the cofferdams simultaneously over their whole length. Only the erection of a 1.2 km length of earthfill dam across the Volga was left for the second construction stage.

Thanks to the concerted efforts of an army of 30,000 builders, and the use of modern construction methods, the duration of construction and the investment cost were kept to a minimum.

The Nurekskii Hydro Development

The economy of Tadzhikistan and the neighboring republics will receive a fillip by the construction of the Nurekskii hydro development, "The Gem of Central Asia". This will be erected on the mountain river, the Vakhsh, in the western spur of the Pamirs. This project, which started in 1961, will furnish water to more than a million hectares of cultivable land in Tadzhikistan[14]. HV lines from this plant will bridge mountains and valleys bringing light and heat to the people of Tadzhikistan and the neighboring areas.

The Vakhsh, a tributary of the Amu—Darya, is fed by glaciers and mountain rivers and is characterized by considerable seasonal runoff fluctuations: from as low as 150 m^3/sec during the winter to 4000 m^3/sec during the summer, after the mountain snows melt. The streamflow during this season has a wild character — the name "Vakhsh" means "wild".

The site of the dam and powerhouse is near the village of Nurek at the narrowest part of the Pulisangin Gorge. This has a depth of 500 m; the bed drops 100 m over a very short distance. The river width at the station site is not more than 12 m with a depth reaching 40 m in places. The streamflow is of tremendous speed, carrying with it boulders whose weight would be measured in tons. The discharge reaches up to 5000 m^3/sec!

The Nurekskii project is to comprise a rock-fill dam, an outdoor powerhouse for nine turbine units fed through three supply tunnels 10 to 11 m in diameter, and a spillway dam handling a discharge of 4000 m^3/sec. Streamflow during the construction period is diverted through two diversion tunnels, each about 1.3 km long.

The dam (see Figure 56) has a clay core. The rock-fill has a volume of 34 million m^3, the volume of the core is 7 million m^3, and that of the sand and gravel intermediate zone 4 million m^3. The dam has a crest length of about 1 km; the height is a record 291 m[15].

The limestone and sandstone quarries from which material for the rock-fill are to be taken, and the clay deposits for the core, are not far from the construction site. It is intended to place the rock-fill in layers of 25 to 50 cm, and to compact them by means of water giants [sic].

The rocky sides of the canyon will house the storage lake, a location for which was created by nature herself: in the upstream direction the Pulisangin Gorge widens, creating a location for the lake which, with a relatively small surface area, will have a holding capacity of about 10 billion m^3. The area to be flooded by the artificial lake has neither important vegetation nor settlements, and there will therefore be no need to relocate inhabitants nor to clear the area of the future lake.

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The Nurekskoe storage lake will be a reliable means of regulating streamflow for the Vakhsh and Amu Darya rivers, ensuring reliable power supply, irrigation, and navigation. The first and most valuable effect of runoff regulation will be the retention of flood discharge, thus diminishing the heavy material losses usually caused by the floods in the adjacent areas. The project provides for the winter drawdown of up to 2 billion m^3 of water.

The installed capacity of Nurekskaya Plant now under construction will exceed the capacity of the Volga Plant im. XXII Congress, by up to 300 Mw (see Figure 74).

Nine 310 Mw turbines will produce about 12 billion kwhr of electricity annually. The design for the giant turbines is being prepared by the Kharkov Turbine Works.

Electricity produced at the plant will enhance the industrial development of Tadzhikistan, an area very rich in natural resources — iron, coal, petroleum, gas, copper, zinc, tin, tungsten, etc.

Plans are under way for the comprehensive electrification of railroads, public transportation, and utility services.

The effect of the construction of the new plant on the development of agriculture will be particularly felt: it will permit the irrigation of more than 2 million ha of arable land in Soviet Central Asia and Southern Kazakhstan. The plant will also make it possible to fulfill an old project — the irrigation of vast tracts of land lying higher than the headwaters of the rivers, or separated from them by mountains. Another advantage of having cheap energy available will be the possibility of pumping water from irrigation ponds located near the land to be irrigated, instead of passing water through hundreds of kilometers of channels.

With the setting up of the new plant, the per-capita production of electricity in Tadzhikistan will be raised by more than 10 times compared with 1960.

The "industrial revolution" in Tadzhikistan where, before the October Revolution, even a simple kerosene lamp in the hut of one of the inhabitants was considered a luxury, vividly illustrates the great changes which the Soviet regime has brought about in the country.

The Nurek, which means "light" or "dawn", will actually be a source of light for the people of Tadzhikistan.

With half the rated head at the dam, the Nurekskaya HEP first supplied current in 1964.

Bratskaya Hydroelectric Plant capacity

Unique in capacity (rated power 4.5 million kw) and in output (21.2 billion kwhr/annum), Bratskaya HEP will be of the utmost importance in the economic exploitation of the vast riches of East Siberia. Cheap electricity from its generators will create a large industrial area in the Bratsk-Taishet Region.

With the other giant hydropower stations — Krasnoyarskaya HEP — Bratskaya HEP will form the backbone of the power system of Siberia.

The water-retaining structures of Bratsk HEP have a length of 5.2 km; they consist of concrete-gravity dams (1.5 km long), an earth dam 720 m long on the left bank, and an earth dam 3000 m long on the right bank (see Figure 40).

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The principal hydrotechnical structure of the plant is the concrete gravity dam, 126 m high, consisting of several sections: one section housing the water intakes for the penstocks (Figure 28); a spillway section with spillway openings (Figure 29); and a nonoverflow section [at the two sides of the dam] adjoining the left-hand and right-hand earth dams.

The powerhouse, 515 m long, is located near the downstream face of the dam. It has 20 Francis turbines of unit power 230 Mw, the rated head being 100 m. The water wheel, which develops a rotational speed of 125 rpm, has a diameter of 5.5 m.

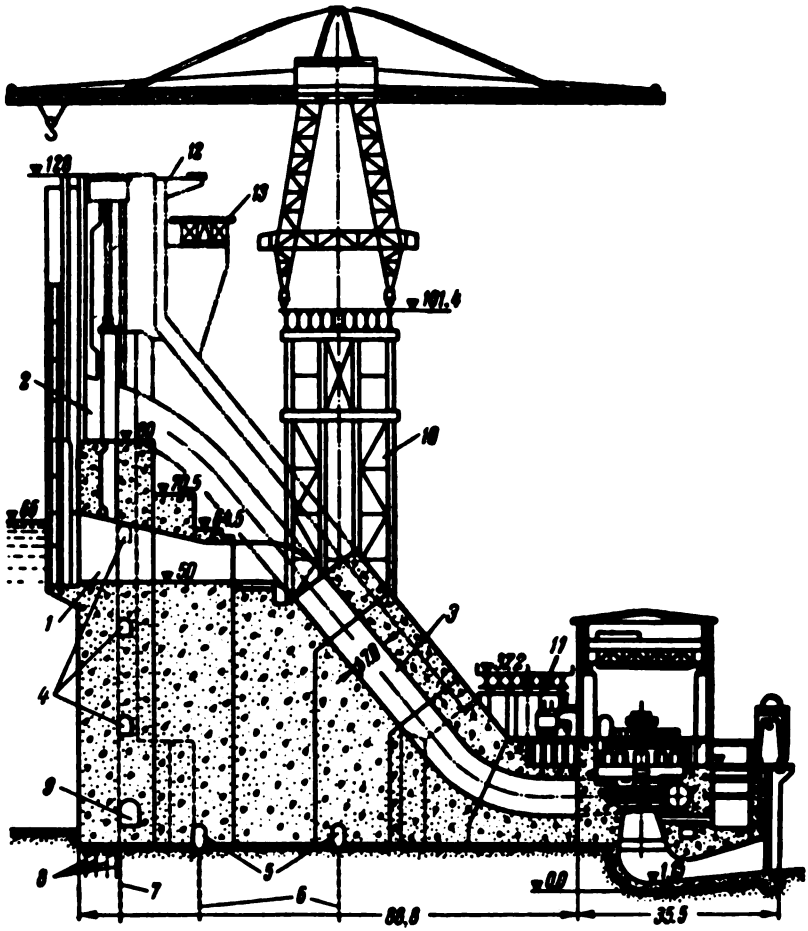

FIGURE 28. Cross section through the Bratsk concrete dam, showing the equipment

1 — provisional water intake (elevation 65 m is the pondage level of the upper pool, for the commissioning of the first unit); 2 — permanent water intake; 3 — turbine penstock; 4 — inspection galleries; 5 — drainage galleries; 6 — drainage wells; 7 — deep grout curtain; 8 — small soil-reinforcing grout curtain; 9 — grouting gallery; 10 — principal concrete-placing trestle; 11 — auxiliary trestle; 12 — railroad bridge; 13 — highway crossing

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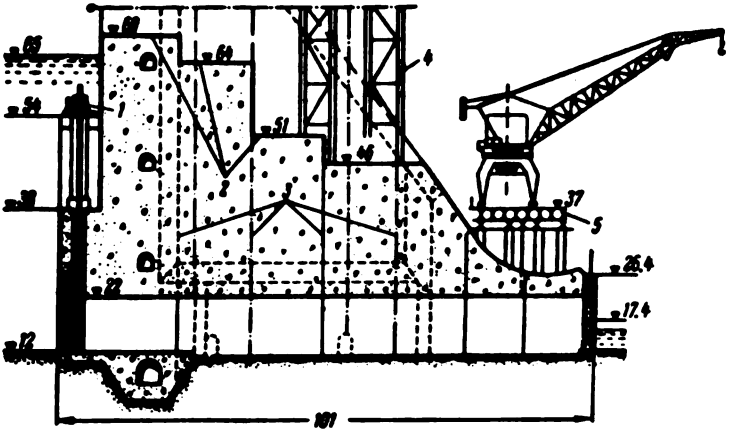

FIGURE 29. Cross section through the spillway section of the Bratsk Dam showing sluiceways

1 — portal-jib crane, 200 ton lifting capacity; 2 — contour of the lower part of the dam (for the first stage of turbine operation); 3 — joints between the structure columns (blocks); 4 — principal concrete-placing trestle; 5 — auxiliary trestle

The storage lake of the plant will be the world's largest artificial reservoir with a total volume of 179.1 billion m^3 and a useful volume (at a drawdown depth of 10 m) of 50 billion m^3. At normal pondage level (122 m) the water surface has an area of 5500 km^2. After the first sluiceway of the spillway dam was closed on 1 September, 1961, the lake started to fill. Filling up to the design level will take 3 to 3.5 years (depending on the runoff during the hydrologic season).

The project involves the following construction work: excavation — 3.4 million m^3; earthfilling — 8 million m^3; rip-rap filling — 1.5 million m^3, concreting — 5 million m^3; and erection of steel structures — 37,000 tons. More than 2.8 million m^3 of concrete will have to be placed prior to the commissioning of the first unit. Most of the concrete (4.37 million m^3) is to go into the concrete run-of-river dam and the river-bank dams; these latter have less steel reinforcing than is usual in concrete structures. The powerhouse and the assembly bay will require 260,000 m^3 of concrete. Of this quantity, 200,000 m^3 must be placed before the first unit is put under load.

Initially, the concrete river dam will not be erected to its full height; only the downstream toe will be completed in the first stage. This will permit an earlier start to be made on filling the lake. Generation will be possible with the reservoir partially filled. For the start of the first six units temporary water intakes are provided, equipped with a retaining sill at a depth of 67 m relative to the normal pondage level of the main lake; the sill is 10 m below the starting lake level for initial operation. The permanent intakes for all turbine units have their sills at a depth of 42 m relative to normal pondage level.

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The erection of the concrete dams is facilitated by the provision of a steel trestle for the conveyance of the concrete mix (Figure 29). The trestle is 90 m high and is equipped with railroad and crane tracks, over which move six cantilever-type concrete-placing cranes, each of 22 ton capacity, with a boom length of 50.5 m. The cranes, manufactured by the Leningrad Machine Works im. S. M. Kirov, will handle two thirds of all the concrete to be placed. The lifting of the concrete to the higher floors of the structures will be done with portal-jib cranes. The cranes ensure a monthly rate of concrete placing of 150,000 m^3.

The unique features of Bratskaya HEP with its giant dam, and the severe climatic conditions of the region, created many difficulties during construction. The lack of experience in the erection of such a high gravity dam, in which the stresses depend on so many variables, made these difficulties harder to cope with. To overcome these problems, the designers and constructors carried out field investigations.

The cofferdams surrounding the excavation pit were constructed, despite difficult hydrologic conditions, during the winter of 1957. Previously, the construction of cofferdams on a river 70% covered by ice, often reaching a thickness of 2 m, was considered impossible.

The dam across the left-hand arm of the Angara River was finished on 19 June, 1959, the work being carried out under hydrological conditions unprecedented in world engineering.

The first turbine unit of the plant was put into operation on 27 October, 1961, and the second unit on 1 November.

During the first stage of operation, the units worked with 50% of the design head, the storage lake containing 17.6 billion m^3, the pondage level standing at 65 m [design level 122 m].

After its completion in 1963, Bratskaya HEP will be the largest hydropower plant in the world. It will always be one of the most impressive structures of Soviet power engineering.

NOTES

[1] Apart from the construction of new hydropower plants, the Seven-Year Plan provides for the expansion of existing plants by installing larger turbine units. Toward the end of the Plan period, the share of hydropower in the total power generated will reach 20%.

[2] Pravda, 11 August, 1958.

[3] The 22nd unit, installed as an addition in 1962, is of particular importance as it embodies a series of novel features aimed at increasing efficiency while reducing requirements of metal, labor, and installation time.

[4] Recent studies showed the possibility of increasing the plant's capacity from 1 to 1.5 million kw.

[5] The rated capacity of the plant — 450 Mw — was raised to 625 Mw without additional investment [by effecting economies].

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[6]On 27 December, 1961, the sixth unit of the Bukhtarmainskaya Plant (75 Mw) started to supply current. The total capacity of the plant at that date was 450 Mw. The yearly output was 900 million kwhr.

[7]Plenary Session of the CPSU, 13-16 June, 1960. Stenographic minutes of the session, p. 317. 1960.

[8]The first concrete placing for the Krasnoyarskaya HEP dam was carried out on 10 August, 1961. The first turbine units were to be put under load in 1965.

[9]On 28 June, 1961, the Ministry for the Construction of Hydroelectric Power Stations approved the harnessing of the Upper Yenisei River and the first stage (six units) of the Sayanskaya HEP (total capacity of 5 million kw).

[10]On 13 February, 1961 the MSES approved the design for the Ingurskaya HEP, the largest plant in Georgia (1400 Mw) with a 300 m high arch dam.

[11]See L. Bernshtein. Opytnaya prilivnaya elektrostantsiya (Experimental Tidal-Power Plant).— Gidrotekhnicheskoe Stroitel'stvo, No. 3. 1962.

[12]Until 1961, 21 turbine units were operating at this plant. Another unit was installed in 1962, as a trial unit. It had smaller dimensions and weight, and water-cooled stator windings, the water circulating through special conductors. The fish lift has four turbine units.

[13]The XXI Extraordinary Congress of the CPSU. Stenographic minutes, Vol. I, p. 40, Gospolitizdat. 1959.

[14]See "Schastie i mir narodam" (Happiness and Peace for the People), p. 291.— Gosplitizdat. 1960.

[15]Some data on large dams of the world: the arch-gravity Boulder Dam has a height of 222 m; the next in height is the gravity dam, Bhakra, India, with 208 m. Under construction are the following dams: the Grand Dixence gravity dam with a height of 284 m and a volume of 5.9 million m^3, the Malvoisin arch dam, height 237, both in Switzerland (cf. F. Nesteruk, Vodnye resursy Indii i ikh ispol'zovanie (India's Water Resources and Their Harnessing).—In: Sbornik "Iz istorii nauki i tekhniki v stranakh Vostoka (History of Science and Technology of Eastern Countries), Vol. I, p. 282, Moskva. 1960. F. Nesteruk. Plotina Bridzh Ken'on (The Bridge Canyon Dam).— Gidrotekhnicheskoe Stroitel'stvo, No. 7, p. 29. 1946.

The Ingurskaya Dam of the Ingurskaya HEP in the Georgian SSR will have a height of 299 m.

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Chapter V

HYDROPOWER CONSTRUCTION IN THE SOCIALIST AND CAPITALIST COUNTRIES

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THE BASIC PRINCIPLES OF HYDROPOWER CONSTRUCTION AS OUTLINED IN THE GOELRO PLAN

The following is an excerpt from the section of the GOELRO Plan which deals with hydropower construction. It is taken from the introductory part of the section and covers guiding principles.

"1. Select the site for the power development so as to ensure optimum conditions for both construction and later operation.

2. In designing a hydro development, try to create a multipurpose project so that the investment will provide several hydrotechnical structures of definite utility; (e. g., combine the use of water for power generation with the construction of locks, irrigation systems, etc.).

3. In designing a hydro development, it is imperative to consider runoff regulation, which is of the greatest importance for steady power generation.

4. Preference should always be given to high-head plants that permit the use of turbine units of lesser weight and smaller powerhouses, involving lower capital cost.

5. If appropriate, try to link the hydropower plant with a thermal station, the latter to be given priority in construction: the building of a thermal station takes less time than that of a hydropower plant. Power will thus become available both to meet increasing demands for electricity and to supply machinery and equipment used in the construction of the hydropower plant[1]."

These five guiding principles from the GOELRO Plan have not lost their significance even today.

In the USSR, hydropower construction is intimately linked with the national economy.

In the USSR, the solution of water-management problems and the design of power-construction projects, is always preceded by a careful investigation of the natural conditions. Various scientific and engineering institutes and agencies participate in this investigation. Thus more than 70 scientific bodies participated in the preparatory work for the construction of the Volga-Don Canal.

Once the construction of a specific project has been decided upon in principle, several alternative designs are put forward. The designs giving the best economic and technical characteristics to the scheme are chosen.

The basic approach of Soviet hydropower engineering is to make a thorough theoretical study of any given hydrotechnical problem so as to find the most rational dimensions and shapes for the structures. However, hydraulics and hydrology are still unable to furnish an adequate theoretical basis for the solution of many practical problems. The use of models and the principles of similarity are bound to play an important role in the solution of these problems. None of the larger hydropower projects in the USSR was constructed without detailed laboratory and field investigations.

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Laboratory research is particularly fruitful in this connection, often leading to entirely new concepts and solutions to problems. Thus, one of the Soviet laboratories developed a novel method of earth-dam construction, without the use of cofferdams, by temporarily diverting the river through a special channel.

Many ideas and projects once believed to be unrealizable, have been, or are on the way to being, translated into fact. At one time, no one would have thought that a direct waterway linking Murmansk in the Far North with Rostov-on-Don would be built. Another example, is the hundreds of kilometers of irrigation channels through the arid sands of the Kara Kum. Soviet constructors undertook the risk of erecting high-head dams on soft ground — literally on sand. High dams have been built on peat soil and on gypsum strata, in Karst regions, etc.[2]

Plans are now being developed to divert the streamflow of the northern rivers, Vychegda and Pechora, into the Kama and thus into the Volga River, thereby increasing the streamflow and the power potential. Other rivers to be diverted are the Siberian rivers Ob, Irtysh, and Yenisei through the Turgai Canyon, into the Aral-Caspian lowland[3].

MULTIPURPOSE HARNESSING OF WATER RESOURCES

The multipurpose harnessing of water resources is a characteristic feature of a socialist economy.

The construction of hydro developments makes it possible to solve simultaneously many economic problems of power generation, navigation, fishery, irrigation, etc.

Combined power-irrigation projects, which may be cited as examples, are the Farkhadskii and Kairakumskii schemes on the Syr Darya River, Chirchik-Bozsuiskii in Uzbekistan, and Sevan-Razdan in Armenia. The existence of the Farkhadskaya HEP ensures the irrigation of 150,000 ha of arid land, while the Kairakumskaya Plant put heart into the famous Golodnaya Steppe [Bet-Pak-Dala].

Other examples of such multipurpose projects are the Volga-Moskva Canal im. Moscow, the Volga-Don Canal, Mingechaurskaya HEP, the giant Volga plants, etc.

The 128 km Volga-Moskva Canal links Moscow, through a wide branching net of waterways, with many harbors of the European part of the USSR. Moscow is now a harbor with access to five seas. The canal, apart from its importance to navigation, increased the streamflow of the Moskva River and its tributaries, thus solving the problem of water supply of the capital. Moreover, the remote-controlled hydropower plants, located along the canal, produce cheap electricity.

Mingechaurskaya HEP, apart from supplying electricity to the industry and agriculture of Azerbaidzhan, is instrumental in solving many hydrologic problems. Thus, its huge storage lake gives long-term runoff regulation of the Kura River, eliminating flood hazard and improving conditions in the lowland regions, once a dangerous malaria center. The water of the storage reservoir is used for the irrigation of about 1,300,000 ha of arid land in the Kura-Araks lowland. Formerly, during summer, the depth of the Kura dropped to 80 cm. Since the building of the plant, the depth does not fall

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below 140 to 160 cm, even in the low-water season. Navigation on the lower reaches of the river has been much improved.

The realization of multipurpose projects is a rather complicated task, as many, often conflicting, aspects of water utilization have to be reconciled. Thus, irrigation and navigation do not need continuous water feed, while drinking-water supply does require this. Various branches of the national economy often make such heavy water-supply demands, that many rivers are unable to satisfy all requirements. In such cases, a decision has to be made as to which branch is to be given priority.

In the USSR, multipurpose water utilization serves the needs of the whole economy. However, there are still instances of insufficient coordination of the various aspects of multipurpose projects. Thus, the hydroelectric plants, Tsimlyanskaya, Volga, Mingechaurskaya, Farkhadskaya, and Kairakumskaya have been in operation a long time; the associated irrigation systems are still awaiting completion. This hampers the economic development of the adjacent areas. Problems of fishery, within the framework of multipurpose projects, are far from being solved satisfactorily. Here, however, the loss to the national economy is offset by higher power output of the electric stations.

Multipurpose projects can only be realized in a socialist economy in which private property is abolished, and all the means of production are nationalized.

A brief survey follows of the state of affairs in capitalist power construction. Lenin once remarked that where the capitalist regime continues, electrification cannot be introduced quickly and in a planned manner, and if it is introduced, then it will not be to the benefit of the workers and peasants[4]

Private economy and capitalism hamper the comprehensive utilization of hydropower resources and the development of power construction. Thus, in Great Britain, the share of hydropower in the total power supply is extremely small, because the large land owners try to prevent the construction of hydropower stations. The same happens in the U.S.A. Thus, a Montana subsidiary of the Morgan-owned American Power and Light Corporation obtained an injunction preventing the development of the available water power of the Missouri Basin. This could have resulted in cheap power production, irrigation, etc. On the other hand, the American Government constructed a series of stations on the Tennessee and Columbia rivers for power supply to the nuclear plants of the Morgans, Rockefellers, etc.

Numerous facts prove how capitalistic monopolies retard the development of power construction. Thus, the designs for the Boulder Dam HEP, prepared as far back as 1922, were approved by the American Government only seven years later.

Construction of another large power station, the Shasta Plant (375 Mw) was started in 1928 but the first stage was commissioned only in 1944. The Grand Coulee Plant, which was started in 1933, was operating at full capacity only 20 years later.

In capitalistic countries, widely publicized projects frequently have to be reconstructed, due to insufficient study of the natural conditions and the lack of planned utilization of the hydropower potential.

As an example, mention may be made of the Aswan Dam on the Nile. The Nile Delta Dam, started some 65 years ago, is still not completed.

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The Aswan Dam, within a period of 32 years (1902-1923) had to be reconstructed three times[5].

Instead of constructing cheap hydropower stations, the British rulers of Egypt built thermal power stations, which burnt British coal, thus benefiting British capitalists. But where it was convenient for the British, they favored the construction of hydropower plants. Such was the case, for example, with the Owen Falls station on Lake Victoria. Here the British built an 80 Mw station, although the potential is much higher; a power of 80 Mw was enough to supply the British mining industry in Uganda.

Although American authors usually pass silently over these contradictions in the capitalistic system, interesting studies sometimes appear that throw light on this state of affairs. An example is a paper published by Professor McIntire, "Utilizing the Energy of Niagara Falls"[6] [title retranslated from Russian].

This paper reveals how the conflicting interests of American monopolies prevented the utilization of the Niagara for power generation. The company-owned hydroelectric plants supply cheap electricity to their own enterprises, while other users receive the more expensive electricity produced in thermal plants. More than 70 years passed from the time the idea of harnessing the Niagara was mooted until a start was made on the Niagara station. How different is the Soviet approach to hydropower construction!

A classic example of the conflicting interests of capitalistic monopolies hampering progress and economic development is the St. Lawrence River project[7].

The plans for harnessing the St. Lawrence were drawn up as far back as the end of the last century. Due to the strong opposition of some influential circles, and the conflicting interests of the companies involved in the realization of this project, it was greatly retarded. After more than half a century of endless discussion and bargaining, the American Government finally decided to start construction.

The situation is no better in other capitalist countries. Thus we read in the British periodical "Engineer" that the hydropower schemes of Grand Dixence and Mauvoisin in Switzerland could have been carried out to greater economic advantage by combining them into a single project. The conflicting interests of various companies using the water of the rivers concerned prevented this.

These brief remarks on the capitalistic countries show clearly that the problems of power construction can only be solved under the conditions of a socialist regime.

THE CREATION OF UNIFIED POWER SYSTEMS

The centralization of power supply, the interconnection of electric power plants through HV transmission lines to form power systems, and the merging of power systems to make a single power pool, are all concepts in line with Lenin's idea of comprehensive electrification of the whole country.

As Lenin wrote "Modern engineering and technology dictate the complete electrification of the USSR and of a series of neighboring countries, in

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accordance with a common plan. Such an idea is not outside the realms of possibility . . ."[8].

The realization of these ideas is possible, if the level of power generation is raised and the whole country covered by a network of transmission lines and substations.

The creation of interconnected power systems is a basic trend of a socialist economy. The first step in the fulfillment of this plan is the creation of regional power systems, later to be tied to interregional power pools.

Much remains to be done in this direction. All the Soviet republics now have power systems which, to an ever-increasing extent, centralize power supply.

Among such interconnected systems, mention should be made of the network connecting the power plants of the Moscow, Gorki, Yaroslavl, Ivanovo, Kalinin, Kaluga, Ryazan, Vladimir, Kostroma, and Kuibyshev Regions. This system covers an area equal in size to Holland, Belgium, Denmark, and Switzerland.

The Ural Power System covers a vast region, stretching over thousands of kilometers from Solikamsk in the Far North to Magnitogorsk in the South. The Southern Power System includes the generating stations of Donbass, the Dnieper Area, and the Rostov District. The capacity of each of these systems exceeds several million kw.

Interconnection is greatly enhanced by the creation of hydroelectric plants, which are very suitable for meeting peak loads, in a system which also includes thermal power stations. In the Central Power System, the Uglichskaya, Rybinskaya, and Gorkovskaya hydro plants are linked to the Moscow, Gorki, Ivanovo, and Yaroslavl systems. The Dnieper Hydro Plant is connected to the Donbass and Dneiper power systems, while the Tsimlyanskaya HEP is linked to the Donbass, Rostov, and Volgograd power systems. The construction of the Mingechaurskaya HEP in the Caucasus favored the creation of the Transcaucasia power pool. The interconnection of the Leningrad and Estonian power systems became possible, only after the construction of the Narvskaya HEP.

Better utilization of installed capacity, and the integration of generating capacity in power systems, in which existing hydropower plants cover peak load demands, led to an increase in the utilization of power-generating equipment (see Table 20).

TABLE 20

Utilization (hours) of power-generating equipment in Soviet regional power plants

Year	1950	1951	1953	1954	1955	1956	1957	1958	1959	1960
Total number of hours at all power plants per year	5994	6052	6032	5972	5903	5766	5385	5444	5500	5377
Ditto, hydropower plants	4537	4576	5016	4308	4700	4525	4703	4717	4329	3855

Creation of a unified power system covering the European part of the USSR became possible after the completion of the two Volga giants — the Volga HEP im. V.I. Lenin and the Volga HEP im. XXII Congress of the CPSU. This accelerated the interconnection of the Central, Ural, and Southern power systems [thus creating the above-mentioned unified power

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system]. Work is under way to interconnect the power systems of Central Siberia, Georgia, Armenia, and Azerbaidzhan.

These systems will form the backbone of the future unified power pool of the USSR, which is now being set up (see Figure 70).

A unified power system for the whole of the USSR will allow more flexible and efficient utilization of installed capacity, particularly as the system will include hydropower plants located on rivers of differing hydrologic characteristics. Thus, two thirds of the yearly river runoff in the lowland section of the European part of the USSR occurs in the months of April through June; while half the yearly streamflow of the Caucasus rivers occurs in the period June-August. These two regions also differ in the recurrence of high-water and low-water years.

The efficiency of utilization of hydropower is enhanced by the interconnection of power systems in which hydroelectric generation normally plays a small part. This refers particularly to the Central, Volga, and Ural systems. Thus, the installed capacity of the Volga HEPs can be used efficiently only by connecting them to the Central, Ural, and Southern power systems. If the Volga HEPs were to feed only the Middle-Volga System, the installed capacity of these plants would have been considerably smaller; this in turn would have resulted in idle discharge of water through the dam. A corresponding need for higher output from thermal plants would arise, increasing fuel consumption.

The existence of a unified power system, comprising both hydroelectric and thermal power plants, markedly increases the efficiency of the hydroelectric plants. It also reduces the size of the equipment reserve, and permits the installation of more powerful, more economical power equipment.

The unified power system of the USSR will be brought into being by interconnecting the individual systems by HV lines. The growth of transmission lines in the period 1913-1965 is shown in Figure 30.

During the first stage of power development (the GOELRO Plan period) the highest transmission-line tension was 110 kv (the Kashira HEP — Moscow line). However, before long, it was recognized that such a voltage level is insufficient to ensure reliable power supply. Therefore, after completion of the Dnieper HEP in 1932, it was decided to erect a 154 kv line. The next step was to 220 kv, used for the first time on the Nizhne-Svir HEP — Leningrad line. The 110 kv lines gradually took on the character of distribution lines.

A step forward in the development of electric transmission in the USSR was the construction of 400 to 500 kv lines, between the large Volga plants and the Moscow and Ural systems.

The 220 kv voltage level proved uneconomical for such long-distance lines. The problem of increasing power loading was studied as far back as 1938. During this period, much scientific research was carried out in the USSR on the design of equipment, and on insulation for 380 kv transmission lines.

The first Soviet 400 kv line from the Kuibyshev Hydropower Plant to Moscow was started in 1949. Entirely new engineering concepts had to be developed, and new types of specification had to be worked out; the acquired experience in operating 154-220 kv lines was helpful to some extent. Careful research showed the possibility of erecting a two-circuit line, capable of transmitting up to 1200 Mw — 6.1 billion kwhr yearly.

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The first circuit of this line was commissioned in April 1956, the second in November of the same year.

In the last few years, more than 2 billion kwhr have been transmitted to the Central power pool over the line, the annual average being 5.25 billion kwhr.

In his plans for electrification, Lenin envisaged the construction of 200 to 400 kv lines that would form a dense network covering the country. The plants to be erected would use peat, water, oil shale, or crude oil[9]. This dream came true. Nowadays, the USSR has a 900 km 400 kv line over which electricity, generated at the giant Volga plants, flows to Moscow.

The first few years of operating the 400 kv line showed its efficiency and reliability. A decision was then adopted to raise the voltage level of the line to 500 kv and the power loading to 1400 to 1800 Mw. No other line in the world has such a high voltage level.

The ever increasing load demands of industry can no longer be satisfied by 500 kv lines, and plans are being made to go above 500 kv a-c, and also to construct HV d-c lines. Direct current has advantages where it is required to provide a reliable tie between power systems, since synchronism of the system then has no bearing on parallel operation; also, the need for special transmission-stabilizing devices is obviated.

The construction of new transmission lines is intimately linked with the construction of new power plants. The increase in line length of transmission lines in the USSR can be seen from Table 21.

TABLE 21

Increase in line length of Soviet transmission lines (835-500 kv)

Type of line	Year						
	1928	1936	1940	1945	1950	1957	1959
Line length, km	2032	16,180	22,482	23,803	32,757	74,812	113,346
including:							
35 kv	500	5,681	8,000	8,465	11,941	20,365	23,910
110 kv	965	7,787	10,575	11,287	16,509	37,310	55,417

At the beginning of 1959, the total length of 35-500 kv lines reached 100,000 km, the yearly increment being 9 to 10 thousand km.

The current Seven-Year Plan provides for the construction of about 200,000 km of transmission lines. About 13,000 km were erected in the first year of the plan period (1959), including the 500 kv line from the Volga HEP im. XXII Congress of the CPSU to Moscow, a distance of 1000 km. The first 800 kv d-c line in the world, from Volgogradskaya HEP to Moscow, was put into service in 1960, followed, in 1961, by a second 500 kv line from the Volga HEP im. XXII Congress to Moscow. Both Volga lines carry over 1500 Mw to the interconnected power systems of the Central Area, which will be one of the most important blocks of the unified power system of the USSR.

C. Ellis, head of an American rural electric corporation, who visited the Soviet Union in 1961, formed a high opinion of Soviet power construction. He expressed the opinion that the USSR would, within a few years, surpass the U.S.A. in this field[10].

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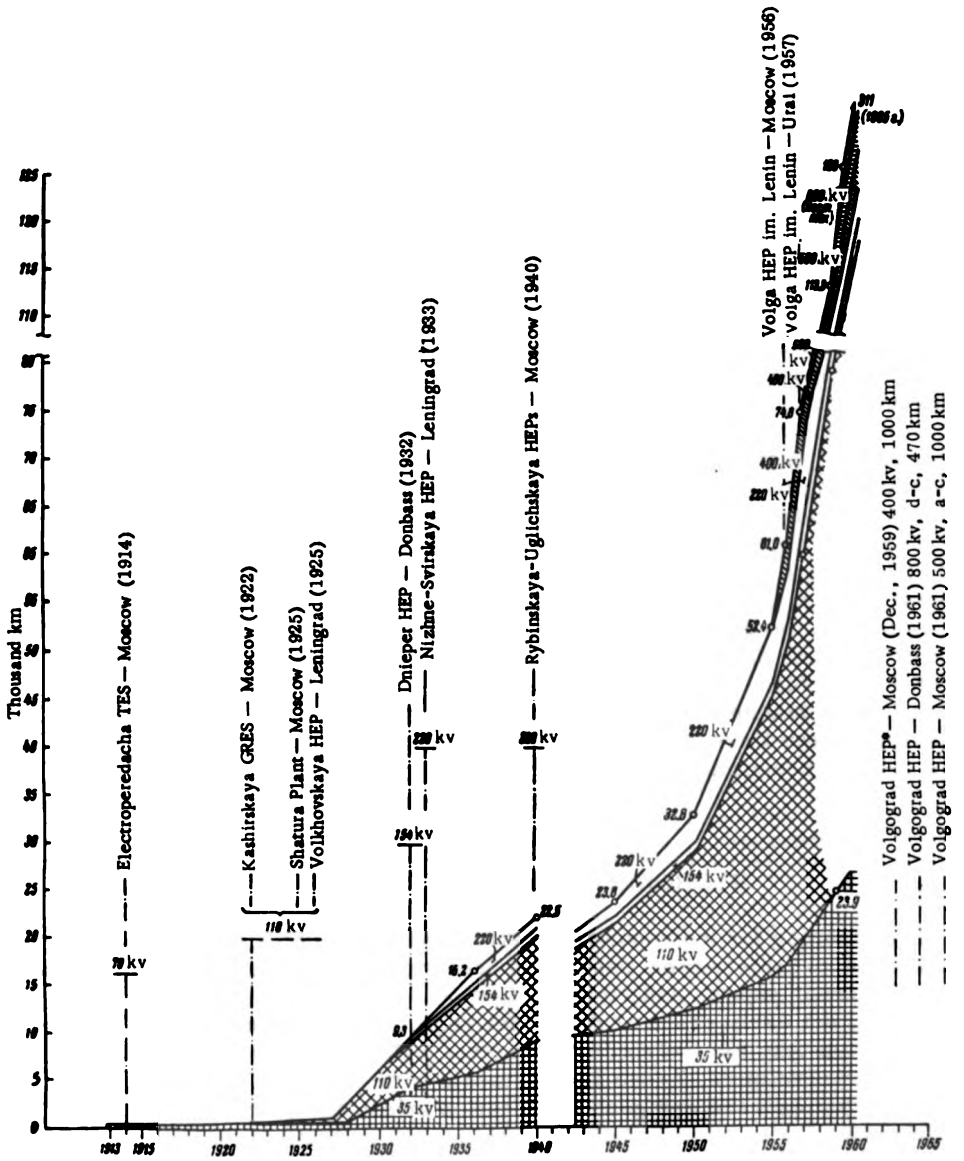
Thousand km
Electroperedacha TES — Moscow (1914)
Kashirskaya GRES — Moscow (1922)
Shatura Plant — Moscow (1925)
Volkhovskaya HEP — Leningrad (1925)
Dnieper HEP — Donbass (1932)
Nizhne-Svirskaya HEP — Leningrad (1933)
Rybinskaya-Uglichskaya HEPs — Moscow (1940)
Volga HEP im. Lenin — Moscow (1956)
Volga HEP im. Lenin — Ural (1957)
70 kv
110 kv
150 kv
220 kv
400 kv
35 kv
Volgograd HEP* — Moscow (Dec., 1959) 400 kv, 1000 km
Volgograd HEP — Donbass (1961) 800 kv, d-c, 470 km
Volgograd HEP — Moscow (1961) 500 kv, a-c, 1000 km

FIGURE 30. Line length and voltage level of Soviet transmission lines (1913-1965)

* [Volga HEP im. XXII Congress of the CPSU.]

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In 1965 — the last year of the Seven-Year Plan — it is intended to reach the target figures by erecting 31,000 km of lines.

By the end of this plan period, electricity supply should cover 70% of the inhabited territory of the USSR.

During the current Seven-Year Plan period, a huge unified power system, which has no precedent anywhere in the world, the European-USSR system will come into being. The power plants of the Central, Ural and South areas, with a total installed capacity of 53,000 Mw, will feed this system. The following large plants will be connected to the system: Volga im. XXII Congress, Volga im. Lenin, Kakhovskaya, Kremenchugskaya, and Tsimlyanskaya. By the end of 1965, the unified power system will cover an area extending from Smolensk in the West to Lyumen in the East, from Kalinin in the north to Odessa in the south.

Another large group of interconnected power networks will be created in Central Siberia, in the area from Irkutsk to Novosibirsk. The total installed capacity will be about 17 million kw, this figure including the largest hydroelectric plants in the world — Krasnoyarsk and Bratsk.

Interconnected power systems will also be created in the northwest, Caucasus, Central Asian, and Kazakhstan regions.

According to the plan, the unified European-USSR power system is to include the whole of this part of the USSR except for the northern area.

The total capacity of the unified power system of Siberia will exceed 50,000 Mw, i.e., more than the power at present produced by the western countries of Europe.

In the not too distant future, it is intended to interconnect the various power systems of the USSR to form a single power system of the USSR (see Figure 70).

It is also planned to widen the international exchange of power, by creating power links with the countries bordering on the Soviet Union. This has obvious economic advantages.

HYDROELECTRIC-POWER CASCADES

The planning for hydropower construction in the USSR gives maximum utilization of waterpower resources and improves the operating conditions of hydropower plants, and river navigation.

During the early years of the Soviet regime, water-management problems were solved only for isolated river basins. Based on research carried out before the revolution, hydro developments with excellent economic characteristics were designed for location at points with maximum difference of level — waterfalls and rapids. Little attention was paid to river control, and large artificial storage lakes were not created. The new hydroelectric plants of the period used almost exclusively the natural (unregulated) runoff of the rivers, e.g., the plants in Zemo-Avchaly and Adzharis-Tskhali.

With the advent of socialist industry, power construction radically changed its scope and goals. From the planning of isolated hydroelectric plants for small river basins, Soviet designers turned to harnessing water resources on a large scale, creating the so-called cascades of river plants. One development plan was drawn up for the multipurpose development of the water resources of a region.

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Since water is capable of yielding useful work along the whole path of its travel down a river channel, the economic advantages of cascade-type developments are self-evident. Such a cascade system, incorporating large storage lakes, ensures optimum regulation of runoff, and hence its optimum use for power generation.

Thus, the commissioning, in 1952, of the Nivskaya HEP in the Arctic Region marked the completion of the Niva cascade of three plants. The new cascade supplies millions of kilowatts to the rapidly expanding power-hungry industry of the peninsula.

Power cascades also improve river navigation, by creating a river channel of a depth which does not drop below a minimum navigable value. This obviates the yearly channel-dredging work which is otherwise indispensable during seasonal runoff fluctuations.

The completion of the Verkhne-Svirskaya HEP — the second stage of the Svir cascade system — has resulted in the water resources of the Svir River being completely utilized. The power supply to Leningrad and navigation on the White Sea-Baltic Sea Canal have both been greatly improved.

In multipurpose projects, the correct selection of the location for and volume of storage lakes is of great importance.

Very few rivers in the USSR have uniform streamflow. Such rivers are the Angara, Niva, Svir and Razdan (Zanga). These rivers flow out of lakes. On other rivers, nonuniformity of streamflow makes necessary the construction of large storage lakes which absorb the spring floods and prevent runoff fluctuations throughout the year.

TABLE 22

Large cascade systems in the USSR

Cascade	Number of plants		
	designed	constructed	under construction
Volga	9	6	2
Kama	4	2	1
Dnieper	6*	3	3
Svir	2	2	—
Niva	3	3	—
White Sea-Baltic Sea	3	3	—
Western Dvina	3	1	2
Neman	8	1	—
Dniester	6	1	2
Sevan-Razdan (Armenia)	9	8	1
Kura-Araks	7	4	—
Rion	12	3	—
Khrami	2	2	—
Sulak	10	1	1
Chirchik-Bozsu (Uzbekistan)	19	13	3
Vakhsh	9	3	1
Ob	8	1	1
Irtysh	13	2	1
Angara	6	2	1
Yenisei	7	—	2

* On the Lower Dnieper

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On lowland rivers, however, large-capacity storage lakes cause flooding and this increases capital cost.

Provided it has sufficient holding capacity, the best economic location for a storage lake is at the headwaters of a river. The water is then used successively by the various plants of the cascade system built downstream.

Cascade power plants are of particular importance in the utilization of lowland rivers, in which spring-high-water discharge represents about 60 % of the yearly discharge.

FIGURE 31. Location of hydroelectric power plants on the Volga and Dnieper rivers.

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The construction of a single power plant [on a lowland river] does not give complete regulation of streamflow; large storage lakes cause the flooding of the adjacent areas, thus increasing the capital cost of the project.

The Dnieper HEP has a storage lake of 1.5 billion m^3 with an annual runoff of 50 billion m^3. The spring runoff is 20-35 billion m^3. The topographical conditions of the site did not permit the creation of an extensive backwater, and this made a large storage lake impossible. The absence of power plants upstream from the Dnieper HEP reduced the economic effectiveness of the Dnieper HEP to a considerable extent: during spring high water, 26% of the mean long-time runoff was idly discharged through the dam, while the mean monthly level of generation of the plant dropped during low-water periods to 150 Mw, sometimes even to 70 Mw. Low-water periods are also dangerous for river navigation.

A decision was made to construct a large hydropower project with a storage lake, upstream from the Dnieper HEP. Only after the completion of the Kremenchugskaya HEP, with a storage lake of 9 billion m^3, was it possible to solve the problems involved in the multipurpose utilization of the Dnieper, and to improve the operation of the Dnieper HEP[11].

The harnessing of the Chirchik River (Central Asia) fed by the glaciers of Ala-Tau is an excellent example of the efficient use of the resources of a water-rich river. It is planned to construct on this river a cascade of 20 hydropower plants. Thirteen plants are already in operation, but these utilize only 51% of the power potential of the river.

This low utilization is explained by the absence of a power plant with a large storage lake.

In the selection of the different sites for the plants of a cascade, a designer usually proceeds from the standpoint of prospective power output, taking into account economic losses due to the flooding of adjacent areas. The building of cascade systems is gradually becoming common practice in Soviet power construction. Many rivers are being fully or at least partially harnessed in cascade schemes (Table 22). The Volga and Dnieper chains of plants (Figure 31) can be taken as typical of the location of cascade schemes.

THE VOLGA-KAMA CASCADE

Volga

The Volga is Europe's largest river system (its total catchment area is 1,380,000 km^2, and the mean annual streamflow is 251 km^3)[12]. It is situated in what is, economically, the most important region of the USSR. Together with its tributaries, the largest of which is the Kama River, the Volga constitutes the main waterway of the European part of the USSR. In terms of cargo haulage, it is the foremost river in the world. Formerly, the Volga could not be used efficiently for navigation, due to considerable fluctuations in runoff, the large number of shoals and sand bars, and to a sharp drop in level which occurred after the passage of flood waves. The first timber dam on the Volga was erected in 1843, upstream from Selizharovka. It created a large storage lake, impounding 400 million m^3, the largest of its kind in Tsarist Russia (the so-called Upper Volga

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beishlot)[13]. Discharge from this lake permitted the level of the Volga to be raised by 20 to 30 cm as far downstream as the town of Tver' (today Kalinin]. In seasons of extremely low runoff, however, this increase was not sufficient to ensure navigable conditions.

A radical improvement in navigation conditions on the Volga was achievable only by the construction of suitable locks. This was done in the early days of the Soviet regime. The GOELRO Plan was instrumental in the transformation of the Volga into the most important waterway in the USSR.

The first of the Volga projects was the Volga-Moskva Canal. Many schemes were drawn up in the period 1931 through 1934 for the harnessing of the Volga and its tributaries. At that time, much controversy existed among the specialists regarding the methods to be used in harnessing the large rivers, in particular, the Volga. Some people supported the regulation of runoff by the construction of storage lakes on the tributaries, the Volga itself was to have low-head dams mainly for navigation purposes, without storage lakes. This would have avoided the flooding of rich land, but reduced the power-generation potential of power plants. Others advocated the idea of constructing cascade plants with large storage lakes, which would give complete runoff regulation and high power output, thus compensating for losses caused by flooding.

After lengthy debate, it was decided to adopt the cascade scheme for the Volga and its largest tributary, the Kama River, thus transforming the Volga into a continuous chain of artificial "river seas" [storage lakes]. Preliminary work on this project, also known as the Bol'shaya Volga* Scheme, was started prior to the war (see Table 23).

The principal features of this project were the following:

1) comprehensive multipurpose utilization of the water resources, (irrigation, water supply, and fishery). No hydro developments to be built without navigational facilities;

2) construction of high-head spillway dams on pervious alluvial ground;

3) maximum concentration of head, i.e., reduction of the number of stages in the cascade scheme, thus improving efficiency and creating larger storage lakes, which give better runoff regulation and utilization of the power potential;

4) particularly careful consideration of the losses due to the flooding of one of the most populous areas of the USSR.

The potential of the Volga and its tributaries is evaluated at 100 billion kwhr per year (corresponding to an installed capacity of 20-25 million kw). Of this, 50% is due to the Volga and Kama rivers alone.

The Bol'shaya Volga Scheme provides for the construction of 13 hydro developments on the Volga and the Kama, to give 11 million kw (50 billion kwhr in a medium-runoff year). Figure 32,a and b show longitudinal profiles of the Volga and Kama rivers, including the sites of these developments.

The total area of the storage lakes created on the rivers will be approximately equal to the surface of the Sea of Azov, while their useful volume (for drawdown) will be 100 km^3. These lakes will impound almost 70% of the volume of floodwater during a medium-runoff year. Runoff regulation will make it possible to use 95% of the available water resources for power generation.

* [Greater Volga.]

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The total area of the land flooded after the creation of the storage lakes will be about 3 million ha (2.24 million in the Volga Area, and 0.8 million in the Kama Area).

Hydropower plants of this project are now producing more than 30 billion kwhr annually (installed capacity 6 million kw).

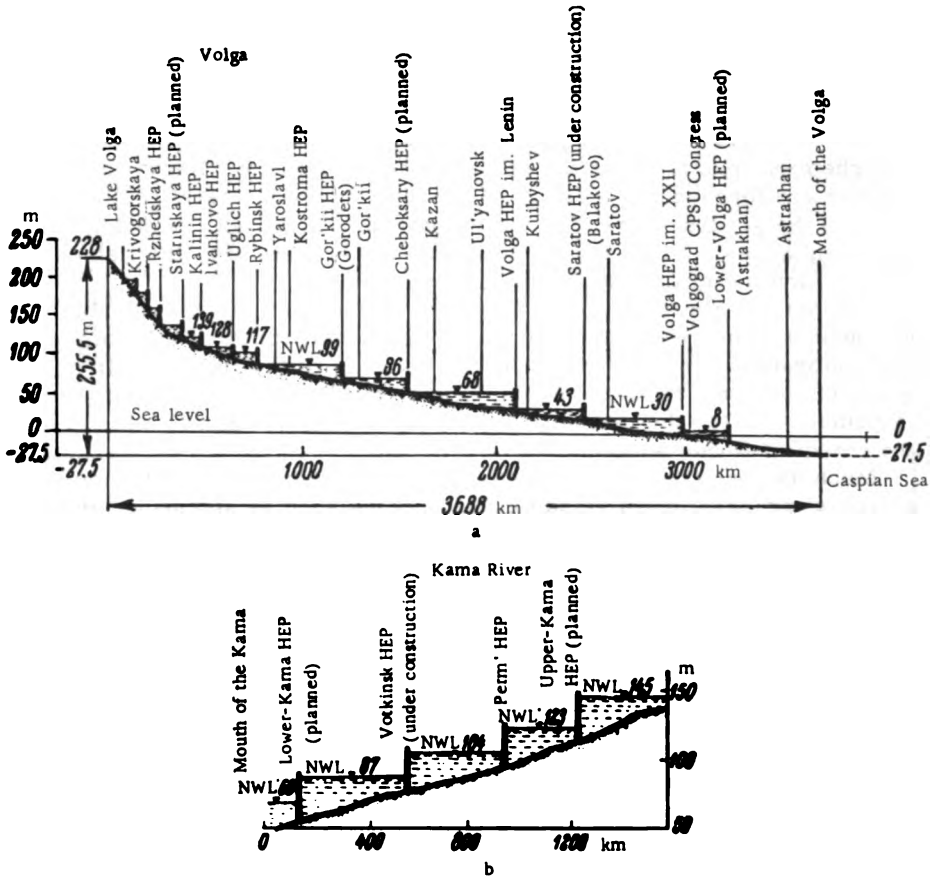

FIGURE 32. The Volga and Kama cascades of hydropower plants

a — longitudinal profile of the Volga; b — longitudinal profile of the Kama.

High-voltage lines from these plants link them with industrial regions in the Central, Ural, and Donbass areas.

The Volga and Kama cascades are of paramount importance for river navigation. The Volga and Kama rivers, with a total length of 18,700 km, of which 4400 km have a guaranteed depth of 2.6 m, were at one time subject to considerable fluctuations in depth. Today these rivers are deep shipways, and are connected to many other independent rivers.

The construction of the development involved the building of new railroads, highways, and river crossings over the Volga. New towns were built, among them Zhigulevsk, and Stavropol (160,000 inhabitants), and Volzhskii (70,000), as part of population-relocation programs.

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Many branches of industry, however, are not yet making full use of the facilities offered by the new developments on the Volga. This refers in particular to agriculture and fishery.

In the most arid zones of the Volga Area, covering 11 million ha, the use of irrigation helped in the reclamation of at least 6-7 million ha of cultivable land. Irrigation channels can easily be fed by pumping stations, supplied with electricity from these developments.

It is intended to erect special fish-processing plants in the Bol'shaya-Volga Area, within the framework of each development. Fishways are planned, for the Volgograd and Astrakhan projects only. Contaminated industrial waste water is a particular danger [to fishery]. Oil-processing and chemical plants cause the most damage to fishery. Heavy losses to fishery are foreseen as a result of the lowering of the level of the Caspian Sea and the gradual retreat of the Volga and Ural deltas, reducing the spawning areas. From the thirties until the present day, the fish catch has dropped from 4 million to 2.6 million centners.*

The natural reproduction of such fish as the particularly valuable sturgeon was markedly affected, after the construction of the Volgograd and Kuibyshev dams, which hinder the passage of the fish to their spawning grounds upstream from the dams. Small-mesh fish also showed a decrease in numbers, after the building of the Volga and Kama dams, which reduced the extent of flooding.

Much has been done in recent years in the study of scientific methods of artificial propagation of valuable fish species such as sturgeon. However, the establishment of special fisheries and fish-processing plants, as envisaged in the projects for the Volga hydro developments, is progressing at a rather slow pace.

Fish catches could be markedly increased in the huge newly created storage lakes; the area of these lakes exceeds 15,500 km^2, equivalent to 40 % of the area of the Sea of Azov.

A short discussion of the construction of the Volga cascade follows.

Ivankovskaya HEP has a small storage lake known as the Moscow Sea. Its volume is 1.1 million m^3, and its area 372 km^2. The lake associated with Uglichskaya HEP has no importance. These two stations are the upper two stages of the cascade.

The third stage of the cascade — Rybinskaya HEP — has a storage lake with a volume of 25.4 billion m^3 (useful volume 11.7 billion m^3), which intercepts the whole of the spring runoff of the Upper Volga and its tributary the Sheksna River. This lake is intended for long-time storage: during the 18 years since the commissioning of the Rybinskaya HEP, spring water has not been discharged through the dam. Periodic discharge through the dam ensures a suitable depth for navigation in the central stretch of the Volga. Prior to the construction of the storage lake, the rise in the water level during heavy spring floods reached a height of 8-10 m near the town of Yaroslavl'. Now, the level fluctuations do not exceed 2-3 m. During low-water, the level is higher than it was before the construction of the dam by 1.5-2 m. The increased depth of the Volga results in the flooding of the rapids on the Mologa and Sheksna rivers. The creation of the Rybinskoe storage lake also reduced the sailing distance between Uglich and Cherepovets by 140 km.

* [A centner is equivalent to 100 kg]

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The next stage of the cascade — the fourth — is Gorkovskaya HEP, with a storage lake of 2.8 billion m^3. The new plant, commissioned in December 1956, solved the problem of reinforcing power supply to the central industrial area, and ensured normal navigation on the middle stretch of the Volga. Periodic discharge from the Rybinskoe storage lake makes it possible to maintain the power output of Gorkovskaya HEP at a steady level.

The construction of the Volga giants — the Volga HEP im. Lenin and the Volga HEP im. XXII Congress of the CPSU — represent considerable progress in the implementation of the cascade project.

The first turbine unit of the Lenin Plant was put into service in December 1955; all 20 of the units were commissioned by the end of 1957.

The water-retaining structures of the new plant raised the level of the Volga 27-28 m above the low-water datum line, creating a storage lake with a volume of 58 billion m^3 and an area of 6450 km^2. The lake extends upstream from the dam to the town of Cheboksary, a distance of 600 km. The width is 40 km. The storage lake, one of the largest in the world, allows the Volga plant to deliver uniform power. This is true, also, of the plants located downstream: Saratov (under construction), the Volga HEP im. XXII Congress of the CPSU, and the Astrakhanskaya Plant (in the design stage).

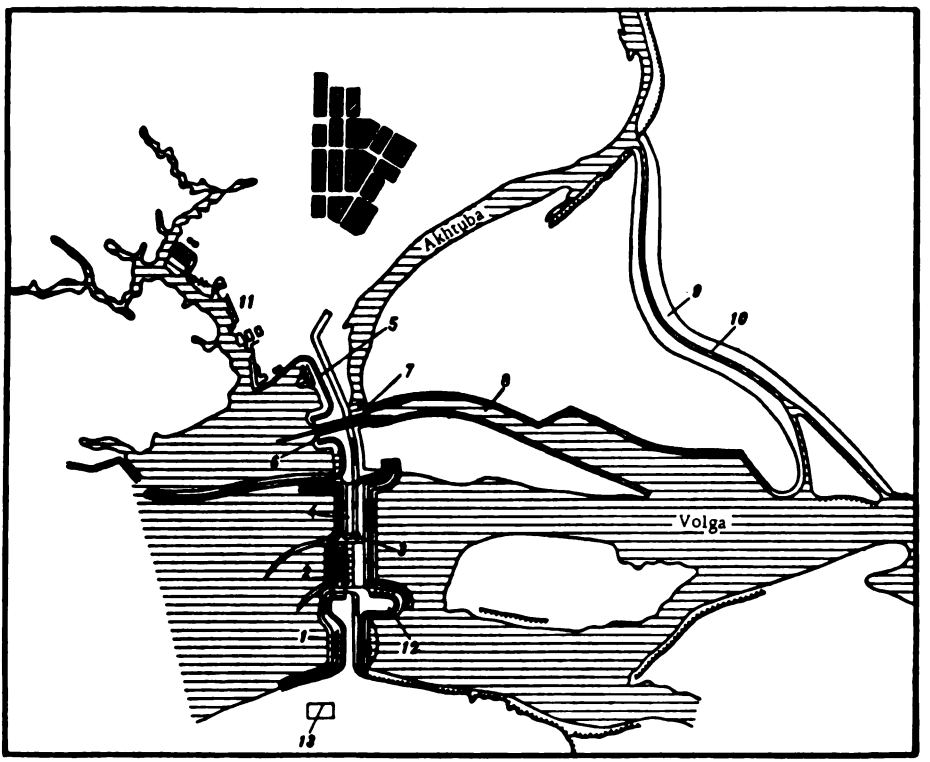

FIGURE 33. Layout of the Volgograd hydro development

1 — earthdam across river; 2 — powerhouse; 3 — fish lift; 4 — spillway dam; 5 — earth dam in flood plain; 6 — ship locks; 7 — water discharge of locks; 8 — downstream navigation canal; 9 — Volga-Akhtuba Canal; 10 — initial cut for canal; 11 — harbor; 12 — 220 kv switchyard; 13 — 500 kv switchyard

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The Volga Plant im. Lenin has an installed capacity of 2300 Mw. During a medium-runoff year, the output is 11 billion kwhr. A thermal power plant of similar capacity would burn about 8 million tons of coal annually.

The Volga HEP im. XXII Congress of the CPSU, farther downstream, is another powerful stage of the Volga cascade (Figure 33). The plant, also known as the Volgograd Hydroelectric Development, is similar in size, head, and details of construction, to the Volga Plant im. Lenin (the Kuibyshev development).

The Volga Plant im. XXII Congress of the CPSU (design capacity 2415 Mw), commissioned (ahead of schedule) in December 1960, is not only the largest plant in the Volga-Kama cascade scheme but one of the largest in the world. Its present capacity — 2563 Mw — comes from the 21 turbine units already in operation, one experimental turbine, and three other units for the fish-lift complex.

The new development comprises the following structures: a powerhouse of built-in type with 22 turbine units; a concrete spillway dam adjoining the powerhouse (one of the bays of this dam — the second from the powerhouse — contains the fish-lift complex, with two fish-guiding flumes on the headwater side, and one on the tailwater side); an earthfill dam crossing the bed of the Volga from the right-hand bank to the assembly bay of the plant; 2 two-stage navigation locks, located in the flood plain between the spillway and the left-hand river bank. The total length of the water-retaining structures is 4900 m, including 1500 m of concrete structures. The various dams create a head of 27 m; they are erected on fine sand and give a spring-high-water discharge of up to 60,000 m^3/sec.

The reservoir of the development has a storage capacity of 32.2 billion m^3 and a length of 500 km. It extends upstream to the town of Volsk. The area of the lake is 3165 km^2, and its maximum width near the town of Kamyshin is 14 km.

The development also includes the Volga-Akhtuba Canal which was necessitated by the closing of the entrance into the Akhtuba River by the structures of the development. The canal route which passes at a distance of 6 km from the axis of the development, has a length of 6.6 km.

The average output of the Volga HEP im. XXII Congress of the CPSU varies between 11 and 14 billion kwhr/year, i.e., it produces annually electrical energy equivalent to 20% of that generated by all Soviet hydropower plants constructed prior to 1960.

The new Volga plant solves a number of economic problems: cheap electricity supply to Moscow, the Volga Area, the Central Chernozem Area, Donbass, etc.; the establishment of a canal system for the irrigation of 1.5 million ha of arid land in the Trans-Volga Area; the creation of the Volga-Ural navigational canal, which also facilitates the irrigation of more than 4.5 million ha of virgin land in the Caspian lowland; and the improvement of navigation on the whole of the lower stretch of the Volga.

Volzhskii, a new town on the left bank of the Volga, has numerous public utilities and facilities.

The new Volga plant ensures proper runoff regulation. The discharge of water through its dams, in quantities in excess of those required for power generation, improves agriculture and fishery in the Akhtuba River plain and the Volga Delta.

Such discharge is permissible in high-runoff years, but is undesirable in medium- and low-runoff years, as it leads to a loss of output amounting

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to 2 billion kwhr. The construction of a special stream divider in front of the Volga Delta would obviate such losses.

The construction of another stage of the Volga cascade, Saratovskaya HEP, was started in 1956 near the town of Balakovo, between the two "Volga" plants. The rating of the new plant is 1.5 million kw. The new power plant will have a concrete spillway dam, twin navigation locks and an earth dam. The storage lake improves navigation between the towns of Volgograd and Kazan', and benefits agriculture by facilitating the irrigation on the arid land.

The Cheboksary HEP, another stage of the Volga cascade, will be erected during the current Seven-Year Plan period on the stretch of the Volga between Gorkovskaya HEP and the storage lake of the Volga HEP im. Lenin. The installed capacity of the plant will be 1.4 million kw.

Apart from generating power, the new development will also permit runoff regulation of the free stretch of the Volga and its tributaries by creating an adequate backwater on the Volga tributaries, Oka, Sura, and Vetluga, which reach the Volga in this area. The creation of Cheboksarskoe storage lake is a very important achievement: construction of artificial lakes on the Oka River involves overcoming certain difficulties.

The completion of the Saratovskaya and Cheboksarskaya plants will transform the Volga into a continuous chain of huge storage lakes, forming a single cascade system of eight hydropower developments, and creating a deep waterway. The construction of this cascade system will harness 86% of the Volga power potential.

Plans are being developed for the construction of four additional power plants on the Volga headwaters upstream from the town of Kalinin. The largest of these will be Kalininskaya HEP (50 Mw): on the lower stretch of the Volga downstream from Volgograd, it is intended to put up another powerful plant, Astrakhanskaya HEP (1600 Mw) (Figure 32).

The Nizhne-Volzhskaya (Astrakhanskaya) HEP, apart from power generation, permits irrigation of the adjacent arid land, and improves the utilization of the rich tracts of land in the Akhtuba flood plain and the Volga Delta.

The Volga-Akhtuba flood plain of the Lower Volga is called the "Golden Valley" because of its natural fertility. The flood plain and the Volga Delta together contain about 2 million ha of fertile land, with another 4 million ha in the adjacent steppe country. Agriculture has not yet been raised above a very low level in this area. Because of protracted floods during the growing season, the use of the extremely fertile land of the flood plain and the delta is impossible unless protecting dikes are built; frequent drought makes intensive irrigation necessary. In this area, irrigation is the main requirement for raising the level of agriculture.

Since ancient times, the Lower Volga and the Caspian Sea have been known for their highly developed fishery. According to A.N. Derzhavin, the well-known ichthyologist, more than 370,000 centners of sturgeon were caught annually in this area during the XVII century. However, due to over fishing, the catch dropped to 100,000 centners a year. To increase the catch of sturgeon, artificial propagation is carried out on a large scale, and artificial spawning grounds have been created downstream from the Vogograd Dam. A new plant, in which highly complex biological experiments are conducted in order to aid artificial first-propagation techniques, has been erected not far from Astrakhan. In 1959, the Kazan fish-breeding station

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produced more than four million young sturgeon from artificially inseminated spawn. Fifteen such stations are required to raise the level of the sturgeon catch in the Caspian Sea to 500,000 centners a year.

The new cascade scheme is of great economic importance. Cheap electricity will enhance industrial development of the area. The electrification of the railroads and agriculture will be introduced, and river navigation will be improved, as a result of the creation of large storage lakes on the Volga and Kama rivers. The width of the navigable waterways will be increased to 500 m or more. A series of new harbors are springing up at the towns of Kazan', Saratov, Ulyanovsk, etc. Kazan', which not long ago was located 5 km from the banks of the Volga, is now becoming a large harbor. Its development is favored by its proximity to Kuibyshevskoe storage lake.

The Volga cascade is helping in the fight with nature. Tens of thousands of hectares are irrigated, and virgin land in the Saratov and Volgograd areas are being reclaimed and cultivated.

A great dream has come true. The Soviet people, freed of its chains, has harnessed the Volga, whose giant power plants supply more power than all the plants of Tsarist Russia together.

The Kama River

"What a mighty river, and how uselessly does its natural strength flow away! From time to time, a wretched ship, a couple of trawlers, a few boats pass; such is navigation on this great waterway".

D. N. Mamin-Sibiryak

Another cascade scheme is being developed on the largest tributary of the Volga — the Kama (see Figure 32). It is intended to erect four hydropower plants with a total capacity of about 3 million kw, to give an annual output of more than 8 billion kwhr. The new scheme will permit 90% of the river potential to be utilized. The Kama will be made navigable for large ships over its whole length.

The first large Ural plant — Permskaya HEP (see Figure 59), was commissioned in 1956. The plant (504 Mw) is located at the confluence of the Chusovaya and Kama rivers. In this area, the annual runoff of the Volga reaches 52 km^2: the maximum spring discharge is 26,000 m^3/sec.

The foundations of the hydrotechnical structures consist of alluvial sand-gravel and clay deposits, underlain by basal rocks. A sand-clay stratum, 8-10 m thick, which contains within it layers of gypsum, lies over limestone deposits. The construction of a water-retaining structure for a head of 21 m, despite such a complicated geological formation, was not a simple undertaking; thorough investigation and survey work had to be undertaken.

The powerhouse of Permskaya HEP is integral with the spillway dam (see Figure 59). The structure permits the passage of spring flood water, at an average discharge of 22,000 m^3/sec, and a peak discharge at the fore apron, of 55,000 m^3/sec. Such a layout reduces the volume of concrete work to half the amount that would be necessary for conventional designs.

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To avoid cutting through the gypsum strata during construction (thus retaining them as a protective layer for the foundation), the over-all dimensions of the turbine units were kept to a minimum: the water wheel had a diameter of only 5 m. The powerhouse, with a length of 400 m, contains 24 turbine units, including an experimental horizontal-shaft turbine. The total power is 504 Mw. Underground water and seepage water are diverted from below the foundation, through special drainage channels and galleries arranged along the upstream toe of the fore apron, i.e., in front of the dam.

The concrete spillway dam, housing the turbine units and other equipment, adjoins the river earthfill dam, which has a volume of 11.5 million m^3. This dam is cut by a navigation lock. Behind the earth dam is the earth dike, which borders the flood plain. The total length of all these dams is 2.5 km, the dam-crest height being 38.5 m.

The storage lake created by the dam has a volume of 10.7 billion m^3 and an area of 1700 km^2.

The Permskaya HEP will supply cheap energy to cover peak-load demands, and save considerable amounts of conventional fuel.

Prior to the construction of Permskaya HEP, electricity for the needs of the Ural Area was generated mainly in thermal-power plants. However, these were insufficient to permit large-scale utilization of the Ural's natural wealth. The new hydropower plant makes good this deficiency, and promotes the development of those branches of industry that are large consumers of electricity.

The Permskaya HEP produces up to 1.75 billion kwhr annually. The future diversion of the northern rivers into the Kama will result in power production going up to 3 billion kwhr a year.

The navigation lock of Permskaya HEP is of a novel design. The lock, which started to operate in 1954, has several chambers and two lanes. This permits the simultaneous lockage of several trains of ships and timber rafts in both directions. Each lane has six chambers to cope with a total head of 21 m. The walls of the lock chambers are made of steel sheet piling, externally lined with lightly reinforced concrete. The length of the lock with approaches is 2.5 km. Timber rafts and ships are towed by electric locomotives on normal-gage tracks run along the lock side.

The new storage lake created by the Permskaya HEP is 250 m long. Its creation effected a marked improvement in navigation and timber rafting on the Kama and its tributaries. Navigation is now possible on the Chusovaya, Sylva, and some other tributaries. Formerly inaccessible localities are now easily approached. The existence of Permskaya Dam permitted the building of a railroad crossing over the Kama.

Another important stage of the Kama cascade scheme, Votkinskaya HEP (1 million kw), started to supply current at the end of 1960. The over-all length of the water-retaining structures is 5.5 km. The storage lake extends 370 km upstream, approaching the Perm Hydro Development. The head at the locks reaches 24 m.

Part of the output from the Votkinskaya Plant is transmitted over a 500 kv line to the town of Sverdlovsk. The plant supplies current to the industry of the Udmurt ASSR, and to the oil fields of Bashkiria. Two 220 kv lines are planned to link the plant with the town of Izhevsk. Votkinskaya HEP will be connected to both the Central and Ural power systems, which form the backbone of the European USSR Power System.

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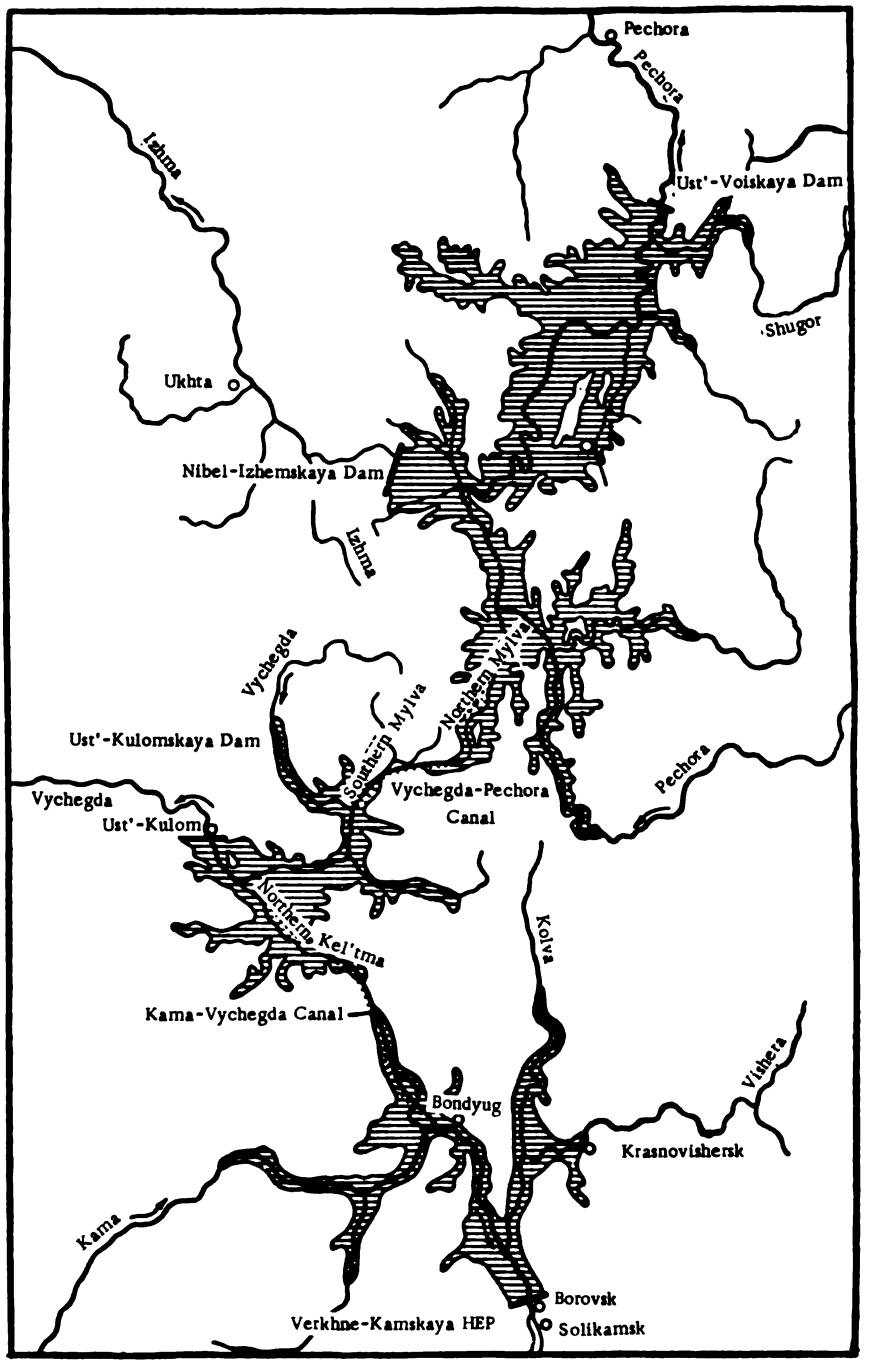

FIGURE 34. Storage lakes and structures for the diversion of the Pechora and Vychegda, through the Kama, into the Volga.

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The last stage of the Kama cascade will be the Nizhne-Kamskaya HEP; the uppermost stage of the cascade, Verkhne-Kamskaya HEP, will be erected at the Kama headwaters.

Nizhne-Kamskaya HEP will be the most powerful plant of the scheme (1.1 million kw). It will export to the Ural system, thus relieving the pressure on and improving the operation of the thermal power plants.

The Nizhne-Kamskoe storage lake will raise the level of the Kama by 15 m, thus permitting runoff regulation and increased power output. The storage lake will also increase the power output of the downstream hydro developments — the Volga, Saratovskaya, and Volgogradskaya power plants — by about 700 million kwhr per year.

The location of the site for the Verkhne-Kamskaya HEP is still under discussion, since it is tied up with problems of diverting some of the northern rivers (the Pechora and Vychegda) into the Kama and Volga.

The installed capacity of the Volga cascade scheme is not yet completely utilized; all the turbines operate only during flood discharge. In autumn, when the discharge through the dam is only 4000 m^3/sec, only 8-12 units of the Volga im. Lenin and Volga im. XXII Congress plants generate; the total number of turbines at each of these plants is 20-21. The output of these plants may be increased without increasing their installed capacity by diverting the runoff of the Pechora and Vychegda into the Kama and Volga[14].

In line with this idea, a plan is being drawn up to create hydro developments near the town of Solikamsk at the Kama headwaters, on the Vychegda River near the village of Ust'-Kulom, and on the Pechora River near the village of Ust'-Voi (Figure 34). The Kama, Vychegda, and Pechora storage lakes will be interconnected by open channels. Through these, the upper reaches of the Pechora and Vychegda will be diverted into the Kama and Volga (annual inflow 40 km^3). Such a diversion will increase the output of electricity from the Volga and Kama cascades by 11 billion kwhr. This increased inflow would occur throughout the year (not merely during spring floods).

The total volume of the "amalgamated" storage lake will be 236 km^3 (useful volume 56 km^3). The area will be 15,500 km^2. The storage lake will allow long-time runoff regulation, without any discharge back into the Pechora and Vychegda.

For this project, 700 million m^3 of rock excavation and 2 million m^3 of concrete placing will be necessary. The new lake will provide a deep waterway for shipping out the products of the forest regions.

The diversion of the northern rivers into the Volga will raise the level of the Caspian Sea. Fluctuations in the level of this sea affect the economy of the area, particularly the oil industry, navigation, and fishery. The level of the Caspian Sea has dropped 2.5 m since 1930.

As a result of the impressive work done in recent years, the Volga is becoming one of the largest inland waterways of the world [being connected to five seas]. Figures on the new Volga scheme are presented in Table 23.

The tributaries of the Volga will be regulated, and the Volga will be united with the Moskva, Don, and Ural rivers to form a continuous water course.

After the completion of regulation and training works, the Volga river basin will become the largest in the world in terms of area, since it will have a surface of more than 9 million km^2, larger than the basin of the Amazon River by a quarter.

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TABLE 23

Characteristics of the Volga and Kama cascade systems
(data collected by Gidroproekt im. S. Ya. Zhuk)

HEP	Available head, m	Annual runoff, km^3	Lake area, km^2	Lake capacity, km^3		Installed capacity, Mw	Output in billion kwhr/year
				total	useful		
Volga							
Ivankovo	11	10	330	1.2	0.9	30	0.12
Uglich	11	14	220	1.3	0.6	110	0.21
Rybinsk	18	36	4550	25.4	11.7	330	1.00
Gorki	13	54	1570	8.7	2.8	400	1.60
Cheboksary	18	112	3780	24.8	15.6	840	3.80
Volga im. Lenin .	24	241	6450	58.0	34.6	2300	11.60
Saratov*	14	247	1950	15.4	—	1000	5.87
Volga im. XXII Congress CPSU* .	22	251	3165	32.2	8.6	2530	11.50
Astrakhan*	17	251	4320	34.5	—	1220	7.19
Kama							
Perm'	19	52	1720	10.7	6.7	504	1.75
Votkinsk	17	54	1120	9.7	2.0	1000	2.00
Nizhne-Kama ...	19	117	5400	45.6	26.1	1400	4.47
Total	203	224	34,575	267.5	101.0	11,664	51.11

* The storage-lake level is stable; the turbines operate on runoff regulated by the upstream storage lake.

PROBLEMS OF THE "LARGE DNIEPER"

The Dnieper is the largest river in the Ukraine and one of the largest in Europe. More than 53 billion m^3 of water annually flow down the Dnieper into the Black Sea. This water would fill a huge lake 5 m deep, 250 km wide, and 400 km long. This water-rich stream, formerly flooding vast tracts of lands, is now being harnessed, and the lights of powerful electricity "factories" — the Dnieper, Kakhovskaya, and Kremenchugskaya power plants — are reflected in its waters.

The Dneprodzerzhinskaya HEP is near completion, and preparatory work has started upstream from this plant, near the Tarasovaya Mts. for the construction of Kanevskaya HEP. Surveyors, geologists, and hydraulic engineers are exploring the site at ancient Vyshgorod, 20 km from Kiev, the capital of the Ukraine, where Kievskaya HEP is to be built. The banks of the Dnieper have become one continuous construction site, from the vast steppes of the Kherson Region to the Polesye Area near the headwaters.

Of the greatest importance to navigation and power engineering is the lower stretch of the Dnieper — from Kiev to the Black Sea. More than 85% of the power potential of the river is available over this section (Figure 31).

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The Lower Dnieper cascade scheme will include the Dnieper, Dneprodzerzhinskaya, Kremenchugskaya, Kanevskaya, and Kievskaya plants. This last will be located near the confluence of the Desna and the Dnieper. The new station is to have an installed capacity of 3.5 million kw, to give an annual output of 10 billion kwhr. The useful capacity of the storage lakes will be 18 km^3.

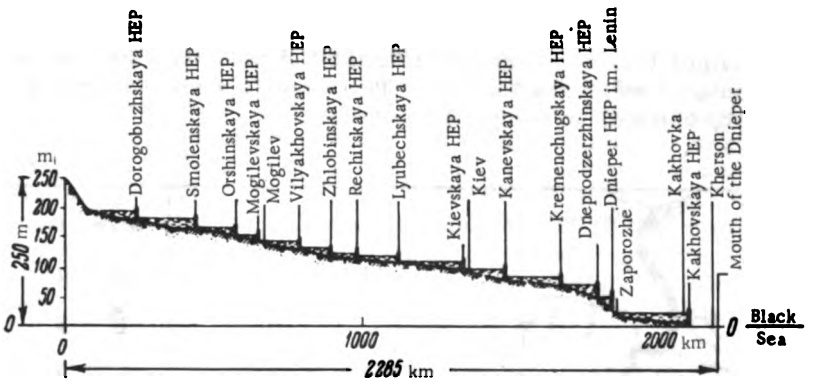

FIGURE 35. Profile of the Dnieper power cascade.

Another cascade scheme upstream from Kiev, consisting of eight smaller plants, will be erected on the headwaters of the Dnieper between Kiev and Dorogobuzh (Figure 35) Thus the total number of hydropower plants on the Dnieper will be fourteen.

The Dnieper cascades will be a further step toward the full harnessing of the river. Its power plants will boost the industrial development of the area, improve navigation, and permit irrigation of more than 3.5 million ha of arid land in the south of the Ukraine and Crimea. Its storage lakes will become an important water-supply source, particularly for the important Krivoi Rog iron deposits. For this purpose, a special supply canal will be constructed originating at the Kakhovskoe storage lake.

At present, three stages of the Dnieper cascade are in operation — the Dnieper, Kakhovskaya, and Kremenchugskaya plants.

The importance of the Dnieper HEP has been stressed earlier in this text.

The Zaporozhe dam raised the level of the Dnieper by more than 37 m and the famous Dnieper Rapids that once divided the river into two halves disappeared for ever. The 2 km long three-chamber locks have made the Dnieper navigable over almost all its length, from the headwaters to the Black Sea. The backwater created by Zaporozhe Dam raised the ground-water level in the Dnieper watershed, thus transforming once arid land into cultivable fields.

The lowermost stage of the Dnieper cascade scheme, Kakhovskaya HEP (see Figure 17), was commissioned to full capacity (312 Mw) in 1956; it supplies 1.4 billion kwhr annually.

The concrete structures of the Kakhovskaya Plant are located on fine-sand strata; the earthdam is built on a 7-8 m thick stratum of loam. The dam raised the level of the Dnieper by 16-17 m, forming a storage lake of

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of 2155 km^2 with a volume of 18 billion m^3. The new storage lake improved navigation downstream from the Dnieper HEP, thus obviating the need for idle discharge. The Kakhovskoe storage lake permits the irrigation of about 2.7 million ha of arid land.

A canal linking the Kakhovskoe storage lake with the Crimea (suggested at the plenary session of the CP of the Ukraine) is now under construction. Its terminus is near the town of Kerch (Figure 36). As an independent entity, the 425 km canal starts at kilometer 61 of the upstream section of the Krasnoznamenskii Canal. The first stretch of the new canal, known as the North Crimea Canal, discharges into the Dzhankoiskoe storage lake (volume 55 million m^3, area 1500 ha). The canal is designed for a discharge of 360 m^3/sec, and will be completed in 1965.

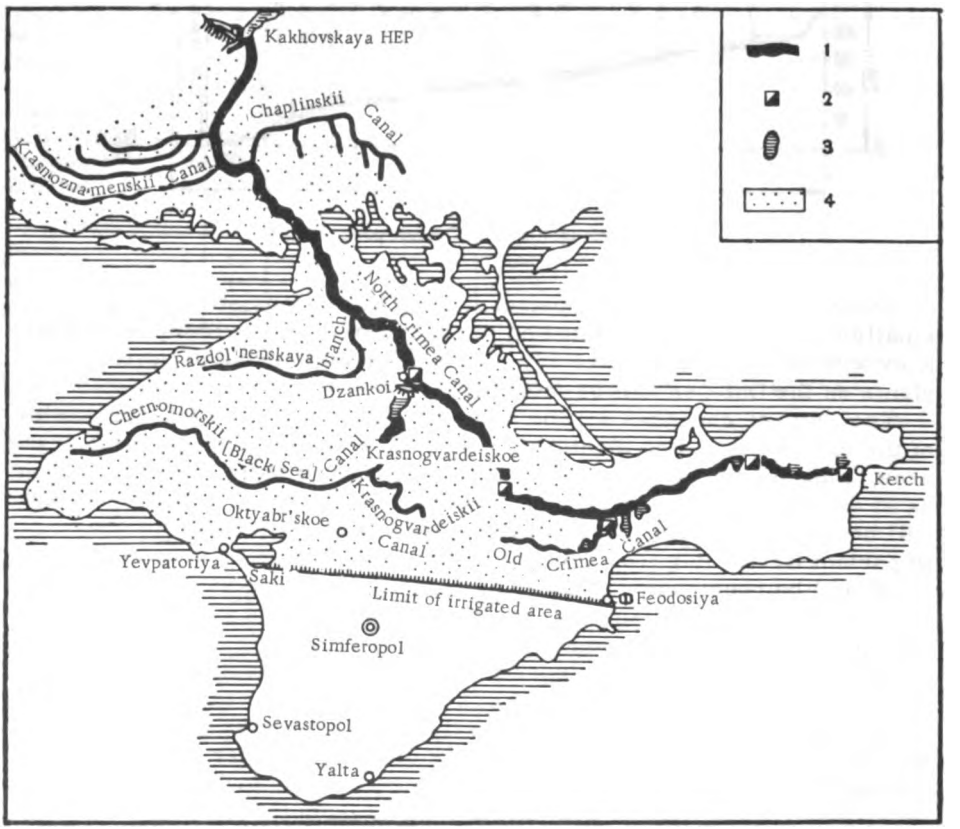

FIGURE 36. The irrigation system of the Crimea

1 — canal route; 2 — large pumping station; 3 — storage lakes; 4 — irrigated area.

The upper stretch is navigable by river ships, which can pass through an intermediate canal 40 km long into the Sea of Azov, and thence into the Don and Volga. The pumping station of the main canal delivers water to

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the Feodosiiskoe storage lake — part of the irrigational works of the canal. Water supply for the town of Kerch and the adjacent area will be derived from the upper section of the canal.

Gorodishche Island, once inhabited by the famous Zaporozhe kossacks, is now a thriving locality with orchards, fields, etc. It is protected against flooding by the Dnieper, by large dikes 7 km long and up to 11 m high. Similar dikes have been erected along the Buzuluk River — a tributary of the Dnieper.

The Kakhovskoe storage lake is the head structure of the Dnieper-Krivoi Rog Canal; the latter has a length of 43 km and was completed in 1961. The canal complex comprises six pumping stations, pressure pipelines, five earthdams with a total length of 29.5 km, bridges, and an overhead-line system with voltages of 6 kv, 35 kv, and 154 kv, and a line length of 110 km. For the first time in Soviet practice, prestressed concrete was used for the pressure pipeline. The construction of the canal involved the excavation of 14 million m^3 of earth and rock, the handling of 77,000 m^3 of plain and reinforced concrete, including 27,000 m^3 of precast concrete. The canal has a useful discharge of 900 million m^3, which is utilized for water supply and for the irrigation of 40,000 ha of land. The canal is to be adapted for navigation.

Another important hydro development on the Dnieper is the Kremenchugskaya HEP, officially inaugurated in December 1959 (Figures 24 and 37). This plant, the first outdoor station in the USSR, has an installed capacity of 625 Mw and a yearly production of about 2 billion kwhr. The development has a storage lake of 13 billion m^3 (six times the volume of the lake of the Dnieper HEP). The Kremenchugskoe storage lake is the main regulating means of the Dnieper cascade; it evenly discharges the spring high water throughout the whole year. This makes possible, without any additional investment, the raising of the annual output of the downstream stations by 700 million kwhr.

The Kremenchugskoe storage lake will become part of the chain of interconnected storage lakes of the Dnieper cascade, thus making possible expansion of Dnieper HEP, by adding six 125 Mw turbine units. For this, 15 spilling bays of the Zaporozhe Dam will be used to feed the additional turbines which will be located behind the dam on the left-hand bank. (The existing powerhouse is on the right-hand bank). The production of electricity in a medium-runoff year will increase by 500 million kwhr.

Kremenchugskaya HEP is connected by transmission lines to the Southern power system (Dneproenergo), and supplies the towns of Kiev, Cherkassy, Poltava, Kharkov, etc., and the associated industrial and rural areas. The new power plants, together with Dnieper HEP, will constitute a reliable power-generating block, capable of handling peak loads in the interconnected power pool.

Kremenchugskoe storage lake, together with the lake of Dneprodzerzhinskaya HEP (commissioned in 1963, with a capacity of 350 Mw) radically changed the character of the Dnieper, which became a continuous deep waterway over a length of 800 km (from Kanevo to the Black Sea).

When the Kremenchugskaya plant was finished, work was transferred to the next plants of the cascade, Kievskaya and Kanevskaya HEPs (the latter having a capacity of 250 Mw).

When all the Dnieper plants are operating at their full rated capacity, the resources of the Dnieper will be 91% utilized.

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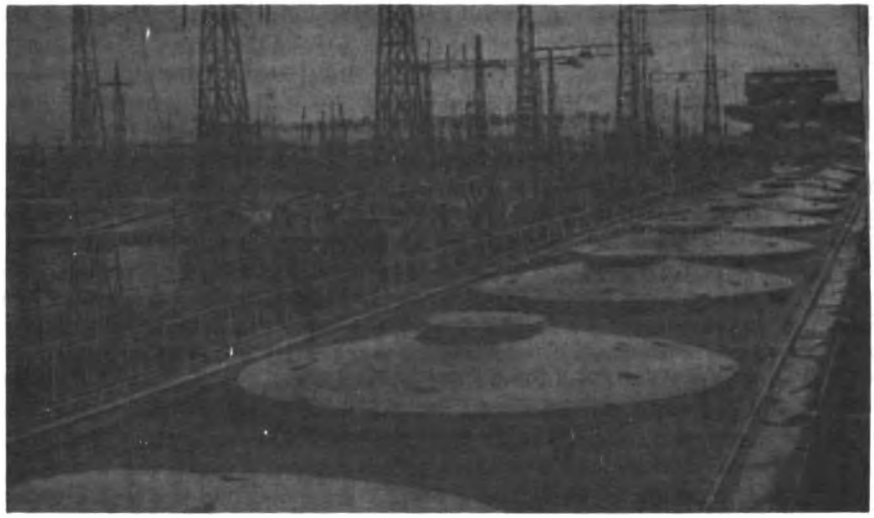

FIGURE 37. Kremenchugskaya HEP showing outdoor turbogenerators covered by protective shields.

With the completion of eight hydro developments on the upper reaches of the Dnieper, the navigation conditions will be considerably improved. The Dnieper is to become a thoroughfare for ships from Kherson to the Caucasus and the Baltic Sea. In the not too distant future, the Dnieper will be linked with both the White Sea-Baltic Sea Canal and the Volga-Moskva Canal.

CASCADE SCHEMES ON SIBERIAN RIVERS

The Communist Party's development plan for Siberia for the next 20 years envisages the creation of new power-generating capacity near the sources of cheap fuel, the harnessing of the Angara and Yenisei rivers, the establishment of industry, etc.[15].

An important, possibly the most important, way of developing Siberia and exploiting the natural wealth of the region is the harnessing of the huge water-rich rivers, the Yenisei, Angara, Ob, and Irtysh. The hydropower potential of these rivers is impressive — 250 billion kwhr per annum.

Sound-rock foundations, relatively narrow river channels, high heads, and ample water discharge, make it possible to construct on the Yenisei and Angara power stations that are more efficient than those put up in other regions of the USSR.

Siberia, once a desolate region, a place for deportation, is changing its face under the Soviet regime. After the completion of the giant power plants, Siberia will produce more electricity than any West European country[16].

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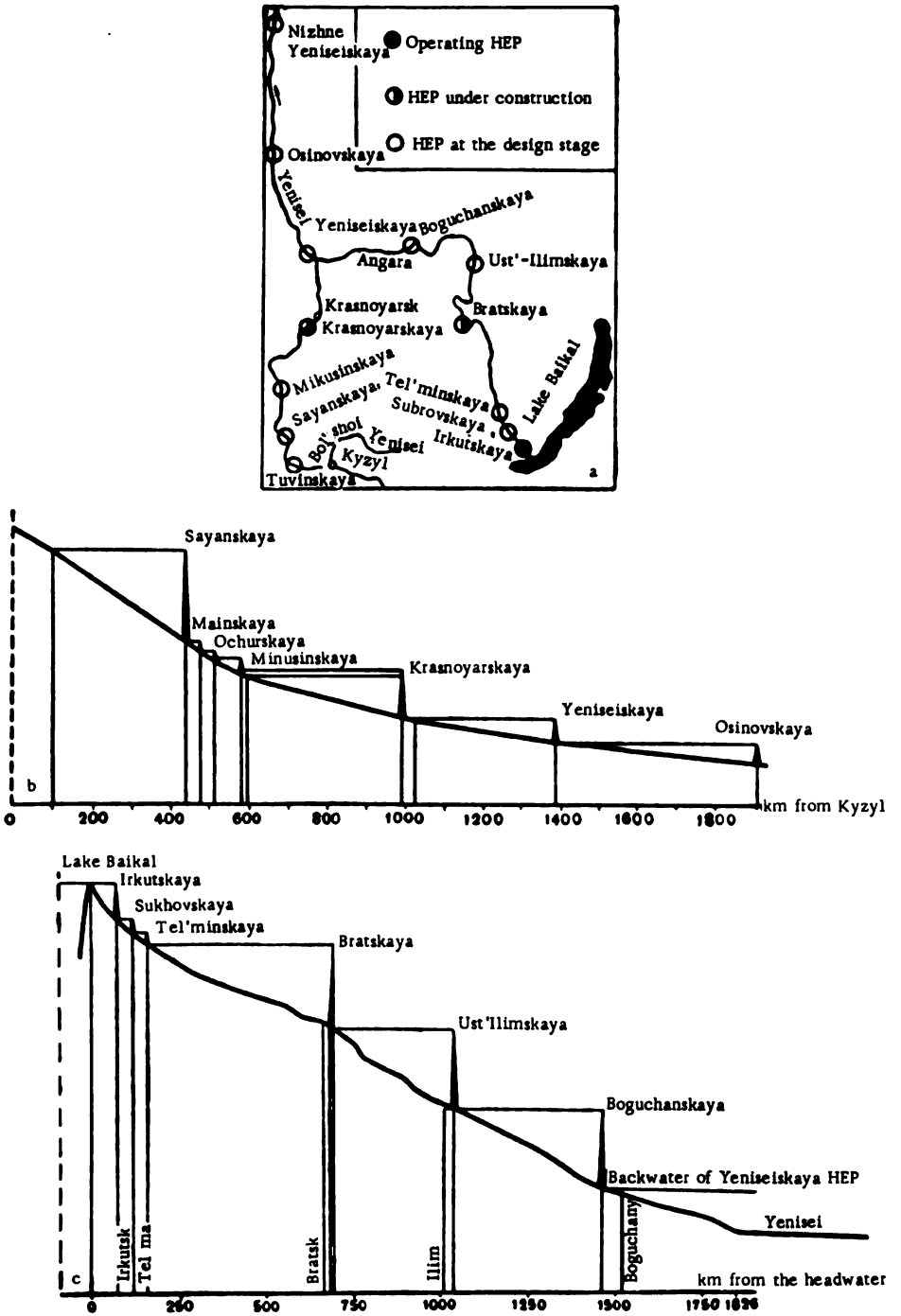

FIGURE 38. The Angara-Yenisei cascade of power plants

a — plan view; b — profile of the Yenisei; c — profile of the Angara.

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Yenisei

The most important element in the development of Siberia is the harnessing of the Yenisei River, the largest Siberian river in terms of watershed area and runoff. The Yenisei has a length of 5940 km, a total drop in level of about 1600 m, and a mean annual runoff of 17,400 m^3/sec, twice that of the Volga and 3.5 times that of the Angara River. During the high-water period, the discharge at the mouth of the Yenisei reaches 180,000 m^3/sec.

The annual runoff of the Yenisei (548 km^3) is twice that of the Volga and ten times that of the Dnieper. The large drop in level of the Yenisei is responsible for its extremely high flow velocity (three times that of the Dnieper and five times that of the Volga).

With a power potential of 57 million kw, corresponding to an annual output of 300 billion kwhr, the Yenisei could produce as much power as was produced in 1960 by all Soviet power plants (thermal and hydraulic).

The cascade on the Yenisei River (excluding the tributaries) consists of seven stages, extending from the town of Kyzyl to the village of Sumarchovo (Figure 38); it will produce about 130 billion kwhr yearly.

The practical harnessing of the Yenisei started with the construction of Krasnoyarskaya HEP (6 million kw). At the site of the plant, the Yenisei has a mean annual runoff of 2800 m^3/sec and a maximum runoff of 29,800 m^3/sec; the narrow valley with its almost vertical rocky banks has a width of only 750 m. The massive concrete dam for the development is 123 m high; the powerhouse with a low (4 m) machine room is provided with hatches in the ceiling above each generator (Figure 53); the inclined ship lift can take ships of up to 2000 tons.

The dam creates a head of 100 m, and a storage lake 380 km long with an area of 2000 km^2 and a volume of 73 billion m^3 (useful volume 30 billion m^3). The start of filling of the lake is scheduled for 1965, the rated level to be reached by August 1966. By this time, the plant should be ready for commissioning.

The dam is twice as high as Niagara. The new plant will be equipped with extremely powerful (508 Mw) Kaplan turbines (Figure 67) (head 95 m, discharge 580 m^3/sec, efficiency 94%). The plant will produce 20 billion kwhr yearly. Krasnoyarsk Power Station will advance the development of industries using locally available raw materials.

Krasnoyarskaya HEP is not the last word in power development in the area. Yeniseiskaya HEP, downstream from the confluence of the Angara and Yenisei rivers, will be even longer. The design capacity — 6 million kw — is greater than the total capacity of all the hydropower plants in the USSR in 1955!

Another stage of the Yenisei cascade — Osinovskaya HEP — will be erected slightly upstream from the confluence of the Stony Tunguska and the Yenisei. With its installed capacity of 5 million kw, and annual output of 30 billion kwhr, it will be one of the largest plants of the cascade.

Angara

Of the Siberian rivers, the Angara offers the most favorable conditions for power generation, thanks to the regulating effect of Lake Baikal, which,

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with a water-storage volume of 23,000 billion m^3, is larger than the Baltic Sea. The Baikal is fed by more than 336 large and small rivers. The only significant outlet is the Angara (1950 m^3/sec), which flows a distance of 1853 km into the Yenisei. Its total drop in level is 378 m or 20.4 cm/km; the drop from Lake Baikal to the Padunskie Rapids is 157 m or 22.5 cm/km.

Compared with the rivers in the European part of the USSR, the Angara has indisputable advantages for hydropower. Thus, the Volga has a drop of only 7 cm/km, the Dnieper — 9.8 cm/km. The peak discharge of the Angara during flood exceeds its minimum discharge by a factor of only 11; for the Yenisei this factor is 66, for the Volga 81, for the Don 195, and for the Dnieper as much as 224. This gives the Angara definite advantages, since the construction of power plants on rivers with large differences between peak and minimum discharge involves additional investment for high dams.

The power potential of the Angara (65 to 70 billion kwhr per year) is greater than that of the Volga, Kama, Dnieper, and Don rivers taken together. The characteristics of the Angara — rocky banks and channel bed — are particularly favorable for the erection of powerful plants.

Plans provide for the construction of a six-plant cascade scheme, with a total installed capacity of 14 million kw (70 billion kwhr per year). Most of the water for these plants will come from Lake Baikal. The new scheme will save yearly more than 50 million tons of fossil fuel.

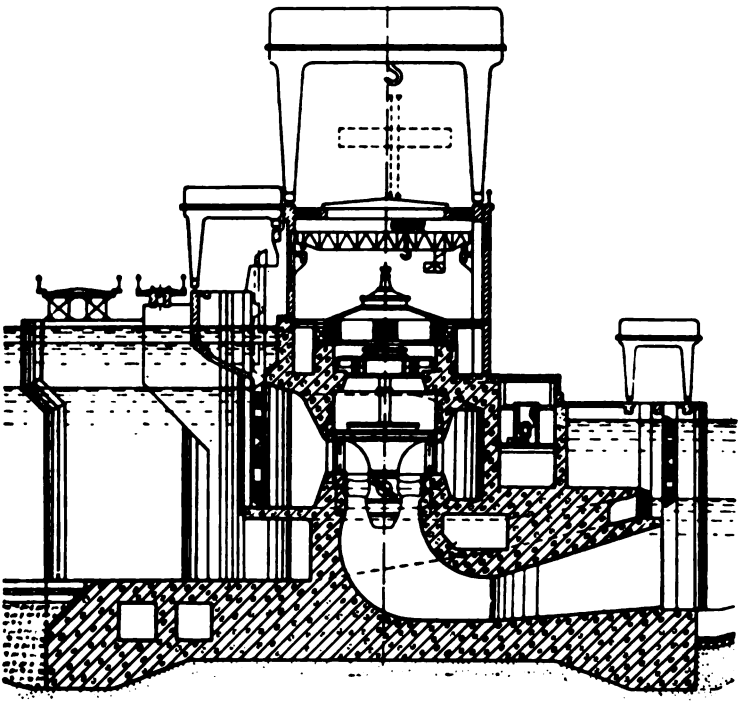

FIGURE 39. Powerhouse of Irkutsk HEP showing built-in water outlets located above the scroll case of the turbines.

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The first stage of the cascade, Irkutskaya HEP (660 Mw), was commissioned in 1956. The 2.6 km long dam of this station is 28 m high. Its construction raised the level of the Angara and created an artificial storage lake. It also increased the level of Lake Baikal by 1 m. On the stretch upstream from the power cascade and close to Lake Baikal — the headwater, the Angara became a forebay of the station with a useful storage capacity of 46 billion m^3. This forebay allows long-term runoff control, and optimum utilization of the installed capacity of the scheme. The degree of runoff control achieved is obvious from the large number of hours of power generation — 3896 for the year (1958). Irkhutskaya HEP produces yearly 4.5 billion kwhr.

The plant does not have a spillway section for the discharge of flood water in the event of Lake Baikal rising above the datum level. Excess discharge is diverted through special outlets (sluiceways) within the powerhouse. These outlets are provided with gates. The powerhouse thus consists of water outlets and the machine room (Figure 39).

Downstream from Irkutskaya HEP on the Angara, another giant — Bratskaya HEP — is nearing completion. The twenty 230 Mw units of this station will give it an installed capacity of 4600 Mw.

At the site of Bratskaya HEP, the Angara suddenly narrows to a width of 850 m, forming the Padunskie Rapids in a gorge 70-80 m deep. This topographical feature permitted the erection of a high dam, and the creation of a huge storage lake, capable of regulating the nonuniform streamflow of the Irkut, Kitoi, Belaya, and Oka rivers — four tributaries which enter the Angara downstream from the site of Irkutskaya HEP.

The Bratsk development (Figure 40) will comprise a concrete run-of-river dam with a height of 126 m (the highest of its type in the USSR), and a concrete section adjoining the right-hand and left-hand earthfill dams. The total length of the water-retaining structures is 5 km. A double-track railroad and a highway will pass over the dam crest. The powerhouse is to be located near the left-hand bank behind the dam. Structures required for river training and navigation will be erected later, when the other upstream and downstream stages of the scheme are built (see Figures 28 and 29).

The dam raises the level of the Angara River by 105 m [at the dam] and creates a storage lake of 179 billion m^3, with a length of 650 km and a width of 25 km. The depth of the Bratsk storage lake varies from 5 to 110 m, its area is 5500 km^2. The complete filling of the reservoir will take 3-3.5 years. More than 38 million m^3 of timber will have to be cut in the area to be flooded.

In a medium-runoff year, Bratskaya HEP will produce 22.6 billion kwhr. Thermal power plants of comparable capacity would have to burn more than 20 million tons of brown coal to produce the same quantity of electricity.

The new development will supply energy to industry in the Bratsk and Irkutsk-Cheremkhovo districts. It is intended to link the station with Krasnoyarskaya HEP. This will enable the varying seasonal demand to be met conveniently.

Cheap electricity from the Angara scheme will permit the development of the new Bratsk-Taishet metal-producing complex. Both the mechanical and chemical branches of a wood-processing industry, one of the largest in the world, will also receive power from the Angara. Near Korshunikha

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(where, as far back as 1654. the cossack Shestachko Korshunov discovered ore deposits and carried out the first iron smelting in this area) an ore-processing plant will be erected. Here, the ore will be transformed into a dry high-grade (60% iron) concentrate.

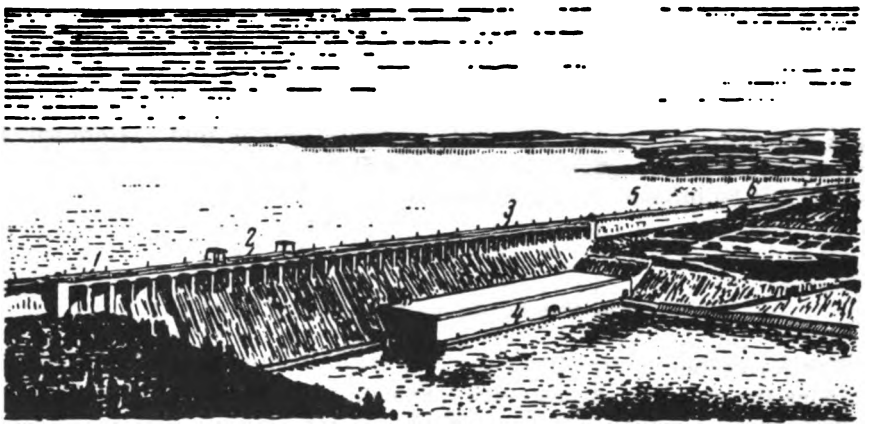

FIGURE 40. Bratskaya HEP

1 — right-hand-bank section of the dam; 2 — concrete spillway section; 3 — powerhouse (non-overflow) section of the dam; 4 — powerhouse; 5 — concrete section of dam; 6 — left-hand-bank earth dam.

The first turbine units of the plant started to deliver current in 1961. The plant was fully commissioned by 1963.

The second and third stages of the Angara scheme — the Sukhovskii and Tel'menskii plants — will be erected between the Irkutskaya and Bratskaya plants.

The site for the fifth stage of the cascade, the Ust'-Ilimskaya Plant, is near the village of Nevon, not far from the confluence of the Ilim and Angara rivers. At this site, the Angara cuts through a thick layer of diabase, which would make an excellent foundation for a dam. The steep banks and relatively narrow width of the channel (800 m) invite the erection of a compact hydro development, which could have good economic characteristics.

According to preliminary calculations, the installed capacity of the new plant could equal that of Bratskaya HEP. Thanks to the excellent geological and meteorological conditions, and the availability of materials, the plant will be erected in a relatively short time.

The turbine units for the plant will have unit capacities in the range 500-600 Mw, and will be among the largest in the world (cf. p. 229).

The Ust'-Ilimskaya Plant will be linked with the Siberian Power System, thus promoting the industrial development of the area, particularly in the field of nonferrous metals.

Calculations have shown that the cost of aluminum obtained from nepheline ores, using cheap electricity from the Ust'-Ilimskaya Plant, will be much less than the average cost of aluminum in the USSR.

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The sixth and last stage of the Angara cascade is Boluchan HEP. It will have a rated capacity of 4000 Mw and is located downstream from the Ust'-Ilimskaya plant.

The Angara Cascade is bound to boost Siberian industry, particularly the metal industry. The huge storage lakes will flood the rapids, thus creating a continuous waterway from the boundaries of Mongolia, via the Selenga River, Lake Baikal, the Angara and Yenisei, into the Kara Sea.

The interconnection of the large Siberian hydropower plants with the thermal power plants of Kuzbass and of other coal basins will be the first stage in the creation of the Siberian Power System, covering the area from Lake Baikal to the Irtysh. The voltages employed in this system will be 220-400 kv or even higher. In time, the Siberian system will reach a capacity of 50 million kw (250-300 billion kwhr a year).

The Ob-Irtysh cascade system (Figure 61)

The watershed of the Ob is the largest of Soviet river basins. It includes the entire West-Siberian lowland, with its extensive untapped resources.

The hydropower potential of the Ob basin is estimated to be 1500 billion kwhr per year (corresponding to an installed capacity of 29.5 million kw).

The annual runoff of the Ob and Irtysh amounts to 394 km^3, i.e., 1.5 times the runoff of the Volga. The Ob has a length of 5569 km with an over-all drop in level of 161 m.

The possibility is being considered of building a cascade of hydroelectric stations on the Ob. The first five stations scheduled for construction on the upper reaches of the Ob (near the Altai Territory, down to the Tom River) will have a total capacity of 1.5 million kw. The lower Ob (down to its efflux into the Gulf of Ob) will be harnessed by a plant of a higher capacity than the Krasnoyarskaya HEP.

The first stage of the cascade — Novosibirskaya HEP (400 Mw) — has been in operation since 1958. Located close to the most important industrial centers of Siberia, this plant produces yearly about 2 billion kwhr, equivalent to 1.4 million tons of Karaganda coal [a medium-grade brown coal].

The Novosibirsk hydro development consists of a powerhouse, concrete spillway dam, river and flood-plain dams, and a three-chamber lock. The water-retaining structures have a length of 5 km. The storage lake, aptly called the Ob Sea, has a length of 230 km, a maximum width of 38 km, a depth of up to 22 m, and a capacity of 9 billion m^3.

Plans are being developed to extend fishery on the lake. More than 3 million pike-perch fry have been transferred from Lake Seliger into the Ob Sea.

The next stage — Kamenskaya HEP — will be erected at a distance of 200 km upstream from the town of Novosibirsk; it will have an installed capacity of 630 Mw.

The large storage lake of Kamenskaya HEP will contribute to runoff control of the Ob River, and increase the output of Novosibirskaya HEP by about 14%. Kamenskaya HEP will also permit the irrigation of more

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than 2 million ha of arid land in the Kulunda steppe and the neighboring regions of Kazakhstan.

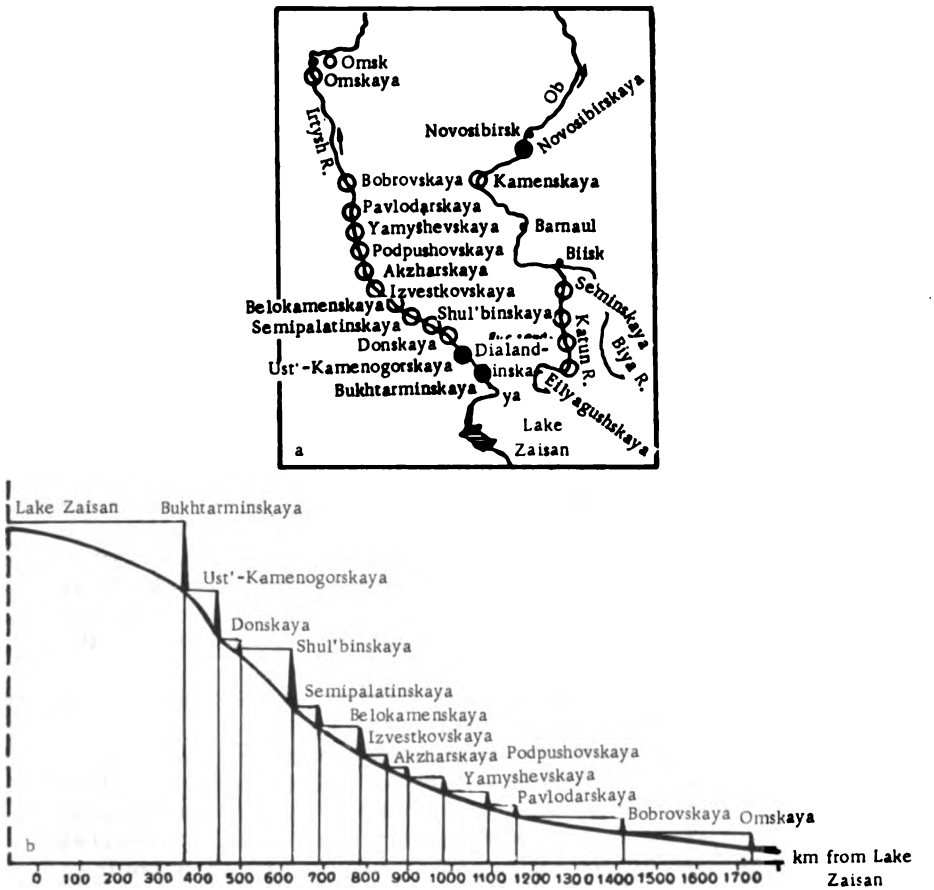

FIGURE 41. The Ob-Irtysh cascade

a — plan view; b — profile of the Irtysh River.

The Ob cascade downstream from Novosibirsk will be supplemented by six power plants: one on the Lower Ob, two on the Upper Ob, and three on the Middle Ob.

Nizhne-Obskaya* Plant (5-6 million kw) is fed by the water-rich Ob and Irtysh, and their tributaries. The plant will be located near the town of Salekhard (on the Arctic Circle).

The Salekhard development will have an earth dam about 12 km long, a 700 m long powerhouse, and 2 two-chamber locks. There will be no spillway dam; spring floodwater will be stored in a huge reservoir of an area of 90,000 km^2 — considerably greater than the area of Lake Baikal.

* [Lower Ob.]

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The Irtysh River

The Irtysh, the largest tributary of the Ob River, has a potential of 28 billion kwhr per year.

The first plant put up on the Irtysh River system was Ul'ba on the Ul'ba River, a tributary of the Irtysh. The plant has been in operation since 1934.

An extremely favorable site for a large power station exists on the Upper Irtysh, between Lake Zaisan and the town of Omsk. More than 70% of the hydropower potential of the Irtysh is available over this 1700 km stretch. Plans provide for the construction of 13 projects (Figure 41,b).

The first plant of the cascade, Ust'-Kamenogorskaya Power Station, was built during the period of the first Five-Year Plan. It has a relatively small storage lake formed by a concrete dam.

Bukhtarminskaya HEP (rated capacity 675 Mw) was completed at the end of 1960, and produces 2.5 billion kwhr in a medium-runoff year.

The plant ensures proper runoff regulation of the Irtysh, and provides a reliable power supply for the Altai mining industry.

The concrete dam of this station, among the largest hydrotechnical structures in the USSR (90 m), raises the level of Lake Zaisan by almost 10 m.

The lake associated with the Bukhtarminskaya also known as the Irtysh Sea, started filling up at the beginning of April 1960[17]. With a surface area of 5500 km^2, the lake holds 53 million m^3 (useful capacity 31 billion m^3). The new artificial lake will completely "swallow" Lake Zaisan, increasing the length of the lake by about 600 km — up to the border of China. It will give uniform power generation at the Bukhtarminskaya Plant, and at the downstream station Ust'-Kamenogorskaya HEP. The installed capacity of the latter will then be used to its full extent.

Bukhtarminskaya HEP will have a four-chamber lock, which will improve navigation over long stretches of the river.

The third stage of the Irtysh cascade, Shul'binskaya HEP, near the town of Semipalatinsk, will be the largest station of the Irtysh cascade. The dam for this plant, to be erected at the point the Irtysh leaves the mountains and flows into the vast lowland of Kazakhstan, will create a large storage lake. This will be used for irrigation (for 10 million ha of arid land).

One of the basic aims of the Irtysh cascade project is the joint operation of the Shul'ba and Bukhtarma developments to give long-time runoff control.

The Irtysh storage lakes will provide a reliable water supply for the large industrial centers of Kazakhstan, Karaganda, Dzhezkazgan, Atasu, etc.

The regulated Irtysh will become a deep waterway. The Irtysh storage lakes, like all other power-plant lakes in the USSR, are used intensively for fishery. Pike-perch introduced from the Aral Sea do very well in the storage lakes of the Ust'-Kamenogorskaya and Bukhtarminskaya plants.

The Ob and its tributaries can be used in the irrigation of the deserts of Soviet Central Asia and Kazakhstan. The Ob will receive water from the Yenisei, from the upper pool of Osinovskaya HEP, across the water divide between the Yenisei and the Ob, via the headwaters of the Bol'shoi Kas and Ket rivers. The efficient harnessing of these two rivers can only be achieved by diverting part of their streamflow.

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The Lena River

The Lena River with its 438 km^3 runoff (being next to the Yenisei in this respect) is almost entirely in the permafrost region. Investigations carried out over the stretch of the Lena from the headwaters downstream to the town of Yakutsk furnished data used in devising the first hydropower schemes for the river (Figure 42).

The head plant of the Lena cascade would be erected near the village of Kaluga. The head is 65 m. The downstream plants — the Zhigolovskaya, Dyadinskaya, Ust'-Kutskaya would operate with a total head of 229 m, while the plants located still further downstream — Kirenskaya, Icherskaya, Nizhne-Vitinskaya, and Zhedaiskaya would have a total available head of only 143 m. The power plants of the Lower Lena, Olekminskaya, Markhachanskaya, Yakutskaya, Aldanskaya, and Vilyuiskaya would have an even lower head — 93 m.

Another plan proposes a single power plant to be erected on the lower stretch of the Lena, which has a length of 1600 km. The plant would have a rated capacity of 20,000 Mw and an annual output of 100 billion kwhr, more than the output of the whole Kama-Volga cascade scheme. The storage lake created by raising the level of the Lena would have an area of 61,000 km^2.

Vilyuiskaya HEP, one of the largest stations in the Lena basin, is being erected on the Vilyui River, a left-hand tributary of the Lena, 1172 km upstream from the mouth.

The discharge of the Vilyui River varies from 13,000 m^3/sec in spring, to 4.3 m^3/sec in low-runoff seasons. In particularly low-runoff years, winter discharge almost ceases altogether. The Lena River basin is in a permafrost region, the thickness of the layer of frozen soil reaching as much as 300 m. At a depth of 10-15 m, the soil temperature is -5° C. In summer, the ground does not thaw to a depth greater than 1-1.5 m. The ground at the site of Vilyuiskaya HEP consists of strong diabase strata.

The runoff regime of the Vilyui River is completely unsuited to the needs of power generation. The bulk of the runoff (97 %) occurs during the summer and only 3 % during the winter. Reliable power generation can only be ensured by creating sufficiently large storage lakes: 5.9 billion m^3 for the first stage, and 19 billion m^3 for the second stage. The storage lakes will have a surface of 770 and 2010 km^2 respectively.

The dam for this development will be of nonoverflow rock-fill type; it will be 67 m high, 560 m long, and contain 2.3 million m^3 of rockfill. The shells have a volume of 650,000 m^3 and will be made of locally available clay. From the storage lake, the water is fed to the turbines through a pressure tunnel, 90 m long and 6.1 m in diameter. The semi-underground powerhouse is equipped with Kaplan turbines. A self-regulating spillway channel (800 m long and 30 m wide at the bottom), is provided for the discharge of flood water. The soil excavated from the channel (1.22 million m^3) is being used for filling the dam. The station will be ready for operation toward the end of the current Seven-Year Plan period.

Another plant of the Lena scheme, Mamakanskaya HEP on the Mamakan River, a tributary of the Vitim, was commissioned in 1962.

A proposal has been made to build a network of navigable waterways to link the Sea of Okhotsk and Laptev Sea. This proposal is now being studied. Such a navigation thoroughfare, consisting of the Lena, Aldan, and Maya

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rivers, could reduce the sailing distance between the European harbors of the USSR and Vladivostok, by at least 3000 km; it would also lengthen the navigation season by half. The Russian writer, I.A. Goncharov, after traveling down the River Maya on the frigate "Pallada", gave an enthusiastic description of the short journey[18].

Studies have been carried out in this area to select sites for power plants on the Aldan and Maya rivers.

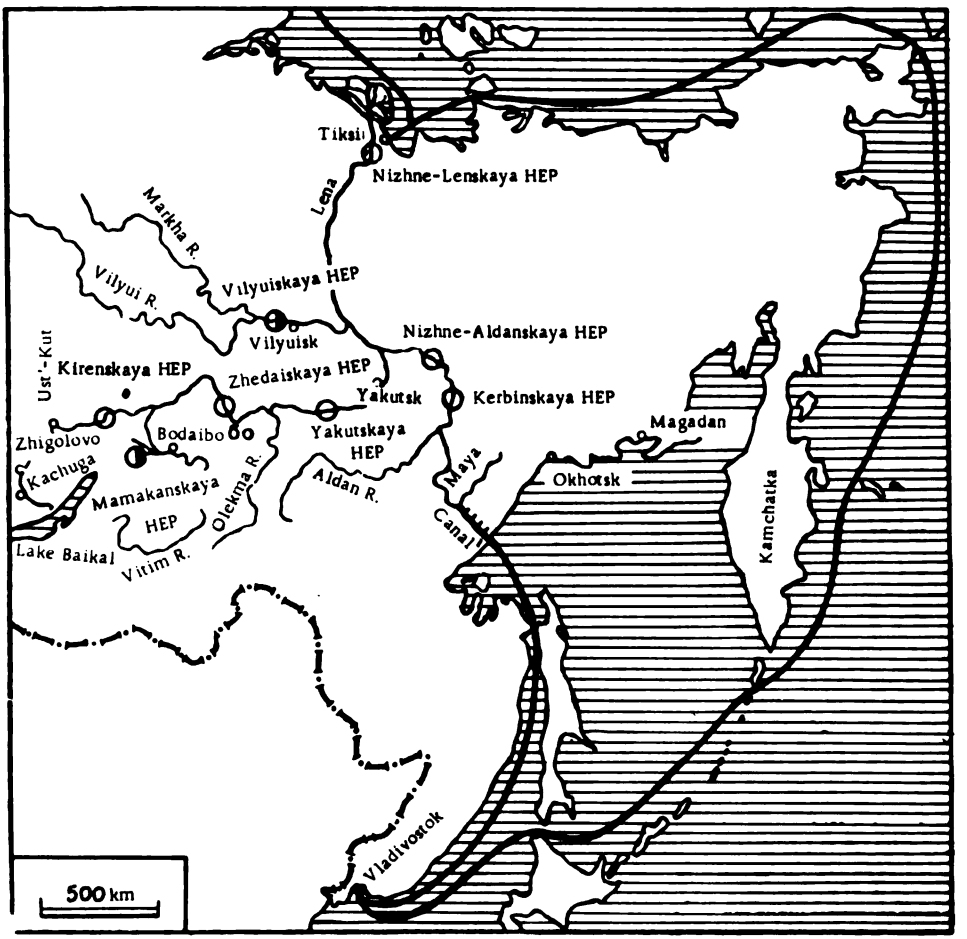

FIGURE 42. The dual-purpose (navigation and power) project on the Lena River.

Yakutia, once one of the most backward areas of Russia, is today an important region for the mining of gold, diamonds, shale, nonferrous metals, etc. The ever-increasing rate of industrialization makes the expansion of power generation imperative (the existing power supply in this area is far from adequate).

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The Sevan-Razdan-Highland cascade system

> "Lake Gochka is able to furnish consistently over 134 million m^3 of water annually. The importance of this lake for irrigation has been recognized since time immemorial; a special survey expedition headed by General Zhilinskii was organized but, unfortunately, the work of the expedition had no practical results."
>
> S E. Serian (Manaseryan). Isparyayushchiesya milliardy i inertnost' russkogo kapitala (Vanishing Billions and the Inertia of Russian Capital), Moskva. 1910. p. 15.

Lake Sevan (formerly known as Lake Gochka) lies in a deep granite hollow, 2000 m above sea level in Central Armenia. With a surface area of 1400 km^2, a length of 20 km, and a maximum depth of 100 m, Lake Sevan is one of the largest mountain lakes in the world. It acts as a "collector" for more than 28 rivers and rivulets. Only a single river, the Razdan (Zanga), leaves the lake.

The huge hollow, filled with more than 58 billion m^3 of water, could have been an excellent source of irrigation in Tsarist Russia, but, like other ideas at that time, it was abandoned. This was a great pity, since Lake Sevan loses 1200 million m^3 yearly by evaporation; only 120 million m^3 leave the lake down the Zanga River.

A proposal to harness Lake Sevan was originally made a long time ago. One of the first to have suggested the use of this lake for irrigation was General I.N. Zhilinskii (in 1892).

A few years later (1909) the writer Serian (Manaseryan) proposed that the level of the lake be lowered by 55 m. This would reduce evaporation and increase the streamflow of the Razdan River. He assumed that by lowering the lake level to a certain minimum, evaporation would drop, and an equilibrium be established between inflow and outflow.

Lake Sevan actually consists of two parts: Greater Sevan, which is shallow and has a surface area of 1000 km^2, and Lesser Sevan, which is deep and has a surface area of only 400 km^2. Manaseryan suggested that Greater Sevan be dried up completely. This would lead to the lowering of the water table by 55 m, and result in a very considerable reduction (by 5/6ths)* in evaporation from the surface.

After the October Revolution, a start was made on implementing these proposals. After a thorough investigation, a comprehensive plan for the utilization of the Sevan was drawn up[19].

The project envisages the construction of a water intake, the effect of which would be to lower the lake level, thus reducing evaporation from the lake by about 1 billion m^3 per year. The annual reduction in the level of the lake will be 1 m, the surface dropping to the final level in 50 years. The lake will then have a maximum depth of 50 m and an area of 239 km^2. As a result, evaporation will drop to half* its previous value: instead of being 92 % of the inflow, evaporation will be only 46 %. Thanks to the reduced evaporation rate, the annual usable runoff of the Razdan River will increase from 110 to 700 million m^3 (i.e., by a factor of 6.5). The Araks River will also increase its streamflow.**

* [Not consistent.]

** [The Razdan is a tributary of the Araks.]

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The Razdan River, which has a drop in level of 1096 m over a course of 146 km, will have a cascade scheme built on it. This scheme will have nine hydropower plants with a total capacity of 640 Mw: the Sevanskaya (Ozernaya), Atarbekyanskaya, Gyumushskaya, Arzninskaya, Kanakerskaya, Erevanskaya, Verkhne-Argavandskaya, Nizhne-Argavandskaya, and Noragavitskaya stations (Figure 43).

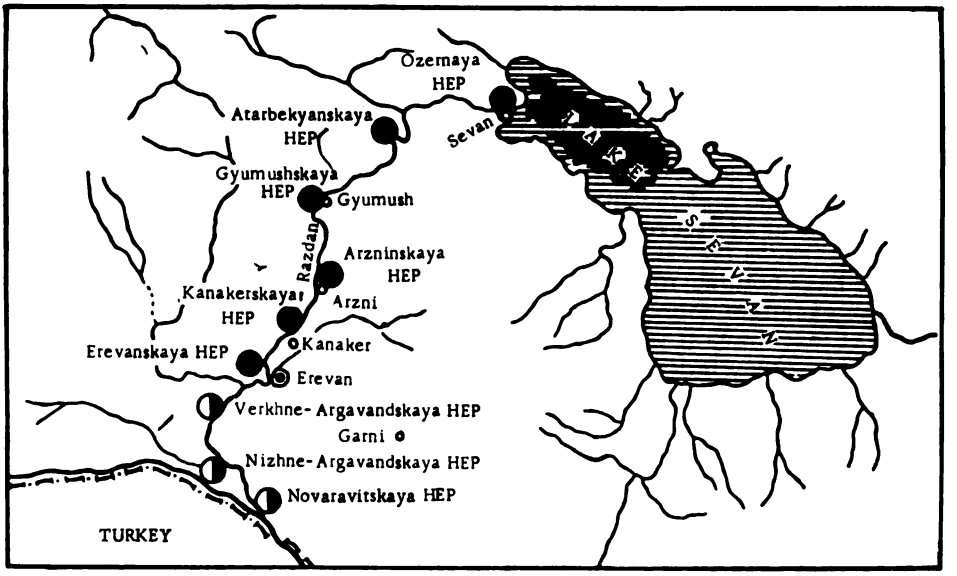

FIGURE 43. The Sevan-Razdan cascade scheme.

The heavier shading shows what the extent of Lake Sevan will be in 50 years time, with the level lowered by 50 m.

Drawdown of the lake waters started in 1936, after the first stage of the cascade, Kanakerskaya HEP, was completed. With the commissioning of subsequent stages, the rate of drawdown is being increased.

In 1946, the waters of Lake Sevan reached the water-intake structure of Sevanskaya HEP, through a channel 1.5 km long. From the water intake, an inclined tunnel carries the water to the turbines of the station — the first Soviet underground station — at a depth of 100 m below ground level. The water discharged through the Sevan plant may also be used for irrigation, for which purpose two large diversion channels have been constructed.

The Sevanskaya and Kanakerskaya plants use almost a fourth of the available head of the Razdan.

The largest stage of the cascade, Gyumushskaya HEP (224 Mw) was commissioned in 1953. The headstructures of the plant consist of a rockfill dam with steel sheet piling, and the water outlet and water intake structures. The gravity-flow diversion structures are an 11.5 km tunnel, and a 7 km channel. The high head of the dam (285 m) indicates the use of Francis turbines (manufactured by the Leningrad Metal Works (see Table 28).

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Another underground power station, the Arzninskaya HEP (the fifth stage of the scheme), was commissioned in 1956. This plant is completely underground. It was built in the record time of only 4 years.

Water flows from the forebay of the Arzninskaya Plant into the irrigation canal of the Arzni-Shamishiramskaya irrigation system, which waters the arid Ararat Valley.

The second and sixth stages of the cascade, the Atarbekyanskaya and Erevanskaya plants, were commissioned in 1958-1959. At that time, work on the three downstream plants was making good progress.

At present, eight of the nine stages of the cascade are operating. All of them are of the diversion type. The total length of their diversion structures (channels and tunnels) is 73 km (47 km of tunnels).

Lake Sevan permits uniform power generation throughout the whole year. During spring high water on the Razdan River and its tributaries, the power plants will operate on the spring discharge only. During low runoff in the summer, the lake will supply most of the water for the plants.

The current Seven-Year Plan provides for the incorporation of the Lake Sevan cascade into the Transcauscasian Power System (Armenia, Georgia, and Azerbaidzhan). As Georgia has no larger bodies of water which can be used for runoff regulation, and as the power output of its generating plants tends to fluctuate throughout the year, the runoff-regulating effect of Lake Sevan will benefit these plants. As stated, the water of the cascade will be used for power generation and for the irrigation of more than 120,000 ha of land in Ararat Valley. Moreover, after the lowering of the water level in Lake Sevan, 120,000 ha of new cultivable land will be exposed.

The power-plant cascade on the Kura River

The Kura River with a length of 1500 km is the largest watercourse in Transcauscasia. It flows through Georgia and Azerbaidzhan — a region characterized by extremely diverse topography and climate which produce a complicated streamflow regimen. The volume of runoff during the months March through July constitutes three quarters of the spring runoff (which amounts to 18 billion m^3). The mean runoff of the Kura River during high water is 600 m^3/sec; during flood it is 2000 m^3/sec. During the winter the runoff drops to 140 m^3/sec.

Four hydropower plants have already been erected on the Kura (Figure 44): the Zemo-Avchal'skaya HEP im. Lenin [also known as ZAGES], commissioned in 1927, and one of the first power plants erected within the framework of the GOELRO Plan, Orkachal'skaya HEP in Georgia, and Mingechaurskaya and Varvarinskaya HEPs in Azerbaidzhan.

The Mingechaur Development, which was completed in 1954, is of great economic importance. It supplies electricity to the industry and agriculture of Azerbaidzhan, and to part of the Baku industrial area. The storage lake created by Mingechaur Dam feeds an irrigation system extending over an area of 1,300,000 ha of arid land in the Kura-Araks lowlands. The storage lake also acts as a runoff regulator for the Kura River, eliminating the danger of flooding in the lower reaches, and improving navigation from the village of Yevlakh down to the mouth.

The Mingechaur Development erected in Boz-Dag Canyon consists of an earth dam 87 m high with a sand and gravel fill of 15 million m^3 (Figure 57),

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and a powerhouse containing turbines with a total capacity of 357 Mw. Incorporated in the dam are the water outlets, water intakes to the turbines, the conduits for the discharge of flood water during the construction period, and the left-hand river-bank spillway section for the discharge of flood water during high run-off years. The volume of the concrete structures within the dam body is 1 million m^3.

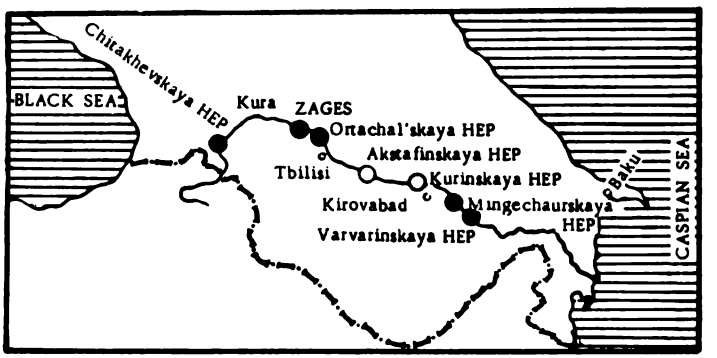

FIGURE 44. The Kura River cascade.

The storage lake, Mingechaur Sea, holds 16 billion m^3 of water, it has a length of 75 km and width of 13 km. Its surface area, 605 km^2, is greater than that of Lake Geneva. The lake feeds the irrigation system made up of the Verkhne-Karabakhskii and Verkhne-Shirvanskii canals. The tunnel which feeds the first of these canals, crosses Boz-Dag Canyon, and has a length of 1 km. The powerhouse erected on the left bank of the Kura contains seven turbine units with a total power of 357 Mw. All the principal units and the auxiliary equipment are automatically controlled. The plant will later be remote controlled from the Azenergo dispatcher center in the city of Baku. Current is transmitted over a 230 km, 220 kv line to the Baku power system. The Varvarinskaya HEP downstream from the Mingechaurskaya plant was commissioned in 1957; it has a power of 16.5 Mw and an 18 m high dam. The storage lake created by the dam also feeds the Verkhne-Karabakhskii and Nizhne-Shirvanskii irrigation canals. The new irrigation system will stimulate agriculture in the area, particularly cotton growing.

The other stages of the Kura cascade are the Akstafinskaya and Tauzskaya plants, three diversion plants on irrigation canals (in Azerbaidzhan), and Agara HEP in Georgia.

Peak demand on the Transcaucasian power system will be met by the Kura cascade plants.

The Kura is very rich in valuable fish species. Since the erection of Mingechaur Dam, fish can no longer travel to their natural spawning grounds at the Kura headwaters. Among steps to be taken to further the development of fishery in this area is the construction of artificial spawning areas.

In order to protect the Kura against contamination by sewage water from the drainage canals, and thus to preserve the valuable fish species, a special channel is being constructed to carry irrigation waste water directly to the Caspian Sea.

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The existence of the large Mingechaurskoe storage lake (area 605 km^2) will also improve climatic conditions in this hot dry area.

Cascade systems on other Soviet rivers

The geology and topography peculiar to the Transcaucasian republic of Georgia are very favorable to an extensive power-construction program. Many of its mountain rivers, such as the Iori, Khrami, Kura, Tkibuli, and Rion have power cascades. Numerous small power stations were built on the canal which connected the Sionna River storage lake with the Tbilisi reservoir. This power cascade fully utilizes the available head of the canal.

Work is in progress on the further expansion of the Rion cascade. Construction of the Khramskaya No. 2 HEP, downstream from the Khramskaya No. 1 plant has started. The new plant has a 13 km pressure tunnel, the longest tunnel driven in the Caucasus area so far[20]. The rated head of the plant is 300 m.

The Rion cascade is to have 12 power plants, of which three — the Rionskaya and two Gumatskaya stations — are already operating.

The Ladzhanurskaya HEP is being built under difficult hydrogeological conditions. A concrete arch dam, 67 m high impounds the water of the Ladzhanuri River while the Tskhenis-Tskali River is being diverted through a 5.5 km inclined tunnel into the Ladzhanuri storage lake, which holds 25 million m^3. The powerhouse is of underground type.

The plans for the harnessing of the Inguri River in Georgia for power generation cover the construction of three hydropower plants. The projects are designed to provide power and irrigation facilities for irrigating the arid land along the lower reaches of the Inguri and Eris-Tskali rivers. Water will also be made available for the year-round agriculture of the Goly District.

The head stage of the Inguri cascade is Ingurskaya HEP, the construction of which was started in 1961. Up-to-date Soviet techniques have been applied in this project, which has an arch dam 299 m high, unprecedented in world power construction; pressure tunnels with a total length of 19 m, including a high-pressure diversion tunnel 15.5 km long, and 11 m in diameter; an underground powerhouse containing turbine units with a total power of 1.4 million kw, one of the largest structures of this kind in the world, surpassed only by the underground powerhouse of the Nechako-Kemano HEP in Canada.

On a 30 km stretch of river, on the tailwater side of this plant, two other hydropower plants will be built — Perepadnaya No. 1 (200 Mw) and Perepadnaya No. 2 (32 Mw). The whole project is to be finished within five years.

Ingurskaya HEP will supply 30 % more energy than the total output of all the hydroelectric and thermal stations of Georgia.

After the completion of the Sevan-Razdan power cascade in Armenia, it is intended to construct a cascade on the Vorotan (Bazar-Chai) River. The first stage of the cascade, Tatevskaya HEP (100 Mw) is now under construction.

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Plans are being developed for the harnessing of the Sulak River in the Dagestan SSR, one of the largest rivers in the Northern Caucasus. The plans include the tributaries of this river, the Andiiskoe, and the Avarskoe Koisu. The scheme involves the building of ten stations with a total capacity of 1575 Mw (6.7 billion kwhr per year). The lowest stage of the cascade, Chir-Yurtskaya HEP, has been completed and its first turbine unit started to deliver current in September 1961.

The largest plant of the Sulak scheme, Chirkeiskaya HEP, is scheduled for construction as part of the 1959-1965 Seven-Year Plan. The site of the plant is downstream from the confluence of the Andiiskoe and the Avarskoe Koisu. The head created by the dam is 210 m, measured from the low-water datum line of the river. The lake has a total capacity of 2.58 billion m^3, useful volume with a drawdown of 40 m — 1.25 billion m^3. The surface area of the lake is 38 km^2. The gorge in which the plant is situated has a bottom width of 10-15 m and a width at the dam crest of 290 m. The bottom and the banks of the gorge are of strong limestone strata.

The Chirkeisk development will have a concrete arch dam, a spillway, water-inlet and outlet tunnels, and an underground powerhouse. Construction will involve 1 million m^3 of surface excavation, 275,000 m^3 of underground excavation, 1,100,000 m^3 of concrete placing, cement grout curtains with a total surface area of 150,000 m^2, and the erection of 12,000 tons of steel structures.

In the Karelian ASSR, the power-construction program is gaining momentum. A powerful cascade scheme is being built along the White Sea-Baltic Sea Canal consisting of the Onda, Vygostrov, and Matkozhnensk hydropower plants.

The Pal'esandal HEP on the Suna River and the Kongopog plant together form a two-stage cascade.

Two power plants are to be erected on the Western Dvina: Plyavinias HEP (825 Mw) in Latvia, Vitebsk HEP in Byelorussia, and Kegums HEP (70 Mw) are three stages of the planned Western-Dvina scheme (Figure 45).

The first stage of the eight-station Neman cascade scheme is Neman HEP (90 Mw), commissioned in 1958 (see Figure 46).

Plans exist for the construction of the Dniester cascade in the Moldavian SSR. Kamenka HEP on the Dniester, now under construction, will be the second stage of the project (the first is the 40 Mw Dubossary plant). The Kamenka plant, upstream from Dubossary HEP, will increase the power output of the latter. Construction has started of Unizh HEP on the upper reaches of the Dniester.

The Dniester cascade scheme is to have an installed capacity of more than 2000 Mw; it will consist of six plants (Figure 47).

Central Asia has huge power resources, sufficient to generate 225 billion kwhr per year. The construction of cascades in this area will increase energy output and permit the broadening of the network of irrigation channels (Figure 48).

As mentioned earlier in this text, the Syr Darya is an important source of power. After completion of Kairakum HEP and Chardari HEP (100 Mw)

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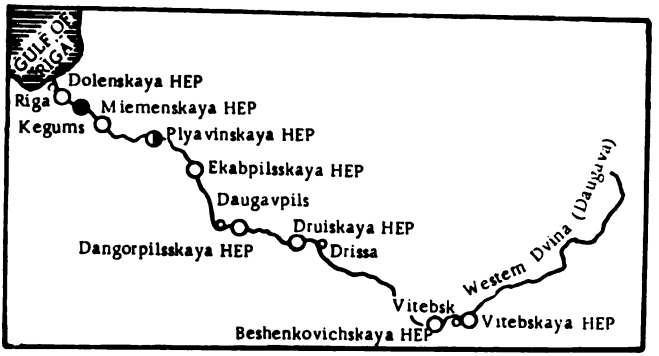

FIGURE 45. Western-Dvina cascade.

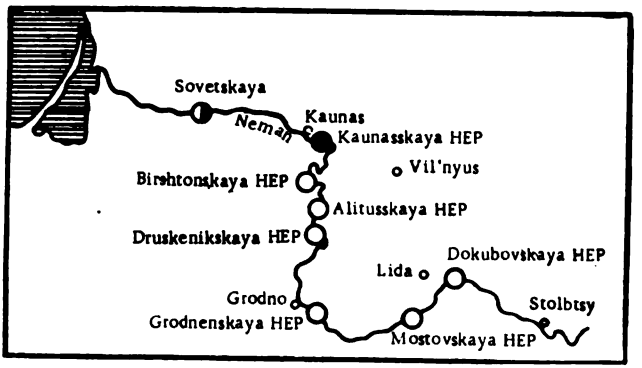

FIGURE 46. Neman River cascade.

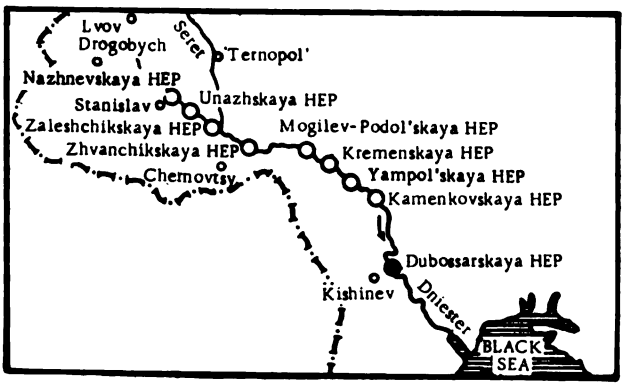

FIGURE 47. Dniester River cascade.

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on the Syr Darya, work will start on the harnessing of the Vakhs River, a tributary of the Syr Darya.

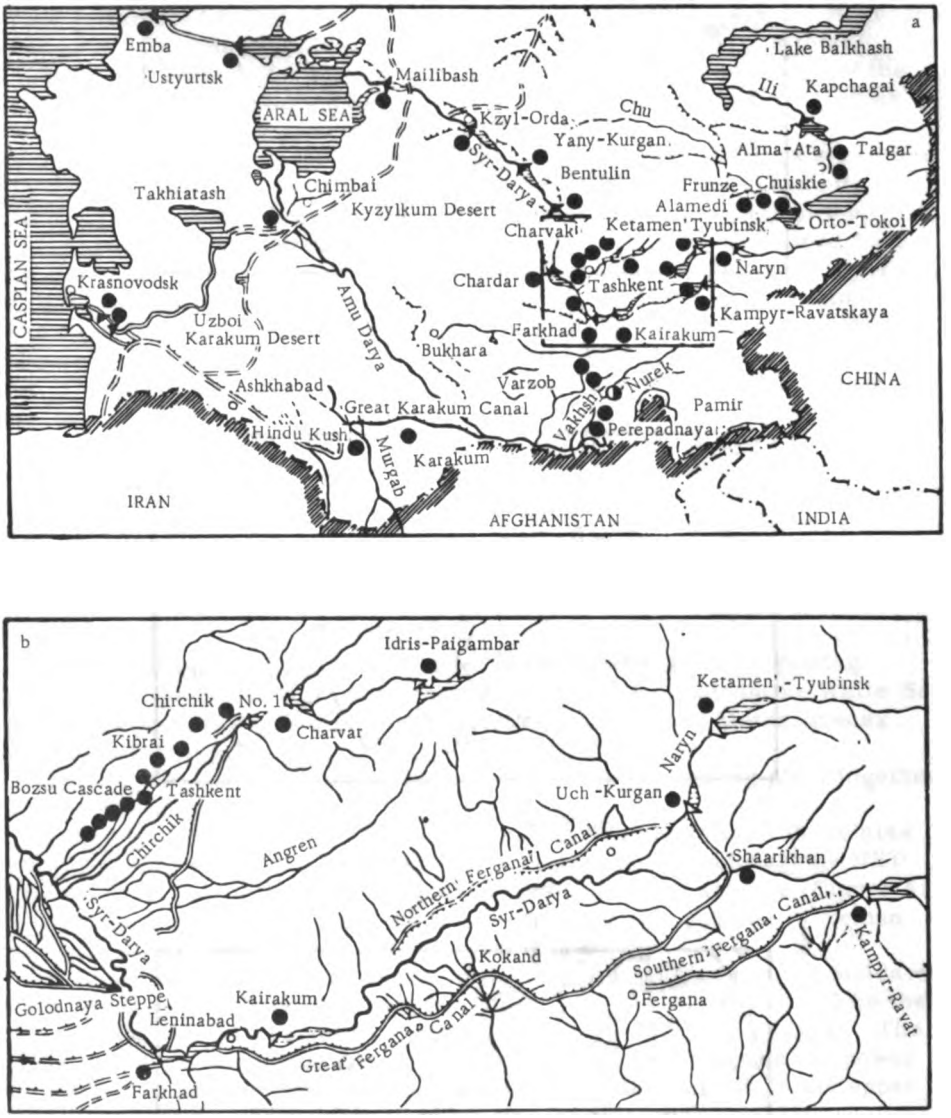

FIGURE 48. Power and irrigation schemes in Central Asia

a — general layout; b — water-management projects of Fergana Valley, the "pearl" of Uzbekistan. (The area shown in (b) is enclosed in a rectangle in (a)).

Perepadnaya HEP (30 Mw), located on the Vakhsh irrigation canal, was commissioned in 1958. Two other plants have been commissioned on this canal: the Golovnaya plant (120 Mw) in 1962, and the Tsentral'naya Plant in 1963. Work has started at the construction site of Nurek HEP, the

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largest stage of the Vakhsh cascade (2700 Mw). Three more stations are to be erected on the Vakhsh with a total capacity of 2500 Mw. These plants will together constitute a reliable source of power, the existence of which will allow the electrification of agriculture and industry in Tadzhikistan and other republics of Soviet Central Asia.

Numerous hydropower plants have been erected along the route of Bozsu Canal: Akkavaksk Nos. 1, 2, and 3 stations, the Bozsu and Salar plants, and many others. At present, the Bozsu cascade comprises 13 operating plants. Further expansion of the cascade scheme is connected with the building of regulating structures on the headwaters of the Chatkala River.

NOTES

[1] Plan elektrifikatsii RSFSR (Plan for the Electrification of the RSFSR), pp. 71-72, Moskva. 1920.

[2] Karst formations occur in regions where the soil contains easily soluble salts and fissured rocks (limestone, gypsum). Karst is characterized by funnel-like sinks, crevices, cracks, caverns, and disappearing rivers.

[3] Programma Kommunisticheskoi Partii Sovetskogo Soyuza (The Program of the CPSU).—Moskva, Izdatel'stvo "Pravda", 1961. p. 73.

[4] Lenin, V.I. Sochineniya (Works), Vol. 33, p. 112.

[5] Nesteruk, F. Problema Assuanskoi plotiny (The Problem of the Aswan Dam).— Gidrotekhnicheskoe Stroitel'stvo, No. 9. 1946.

[6] Economic Geography, No. 3. 1952.

[7] Nesteruk, F. Sovremennoe sostoyanie gidroenergetiki i tendentsii ee razvitiya (The Current Situation and Trends in Hydropower Engineering).— Thesis for the degree of Candidate of Engineering Sciences, Ms., Moskva. 1946.

[8] Lenin, V.I. Sochineniya (Works), Vol. 33, p. 112.

[9] Lenin, V.I. Sochineniya (Works), Vol. 35, p. 370.

[10] Pravda, 2 November, 1960.

[11] Following the interconnection of all the Ukrainian power plants to form a single system, it became possible to increase the installed capacity of the Dnieper HEP, and to use it as a peak-load plant.

[12] 118 km^3 are from the Upper Volga, and 119 km^3 from the Kama River. Downstream from the confluence of the Kama and the Volga, streamflow increases by only 14 km^3.

[13] The storage lake, reconstructed during World War II, is still in use today.

[14] Cf. Volzhskii i Kamskii kaskady gidroelektrostantsii (Hydroelectric Power Stations of the Volga and Kama Cascade Systems), G.A. Russo, Moskva-Leningrad, p. 104. 1960.

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[15] Programma Kommunisticheskoi Partii Sovetskogo Soyuza (Program of the Communist Party of the Soviet Union).— Moskva, p. 69. 1961.

[16] See: Kontrol'nye tsifry razvitiya narodnogo khozyaistva SSSR na 1959-1965 (Target Figures for the Economic Development of the USSR, 1959-1965).— Gospolitizdat, p. 68. 1959.

[17] By 11 October, 1961 the depth of the Bukhtarma storage reservoir had reached 61 m, almost the depth of Lake Zaisan. It contains 25 billion m^3 of water and has a surface area of 3000 km^2.

[18] Goncharov, I.A. Fregat "Pallada" (Frigate "Pallada"), Moskva, p. 605, 1949 [republished].

[19] Lowering the level of a lake for the purposes of power generation is not usual in power construction. It has been done on only two other occasions: in Switzerland the level of a lake was lowered by 29 m, and in France a lake level was lowered 50 m. The water-storage capacity of these lakes is much smaller than that of Lake Sevan.

[20] Tunnel excavation started from four headings; working gallery No. 1, started in 1961, reached a length of 4023 — the longest single gallery ever driven in the USSR.

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Chapter Six

THE IMPACT OF SCIENCE ON THE DEVELOPMENT OF POWER CONSTRUCTION IN THE USSR

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In the USSR science is intimately involved in the development of the national economy and, thus, in power construction[1].

Before the October Revolution, hydropower construction in Russia was rather limited as a result of the economic backwardness of the country. The relatively high level of theoretical research in Tsarist Russia was not utilized in power construction, partly because this was on a small scale, and partly because of a certain lack of confidence in the capabilities of the Russian people.

The progress made in hydropower construction in the USSR is evident not only from "dry" statistics, but also from qualitative improvements, the research facilities that have been created, and the success obtained in solving a series of hydrotechnical problems. The most important of these problems were in the fields of hydraulics and hydrology, the study of hydrotechnical structures, and the improvement of power equipment.

Hydropower construction cannot expand without solutions being found to a great variety of engineering problems. It has been necessary to master the construction of new types of dams, storage lakes, locks, conduits, etc., and to develop new types of equipment and structures called for by the conditions existing in the USSR, and unknown abroad.

Modern hydropower construction, involving, as it does, runoff control and hence large storage lakes, is dependent on the design of high dams of various types.

The increasing rate of construction in the USSR requires quick, cheap construction methods. The most pressing problem in the field of structure design is to find a way of mechanizing and speeding up the production process and reducing costs, without reducing reliability and utility.

The necessity arose of finding design principles for dams of medium height for erection on soft foundations (characteristic conditions for most Soviet dams), and for dams made of locally available material. These principles should entail minimum usage of concrete and steel, and result in dams suitable for dual-purpose developments and for the climatic and hydrologic conditions of the USSR.

The construction of spillway dams on soft pervious soil necessitated the study of the hydrologic regime of headwater and tailwater, the stream-flow connection between them, methods for the dissipation of water-energy, for protection against seepage, and for ensuring dam stability.

The construction of water pipelines and structures involved the study of gravity-flow and pressure conduits for rivers subject to heavy icing and silt loading, and the arranging on one river of water intakes for power engineering, irrigation, and water supply.

In the field of river-channel control, it has been necessary to improve methods of river training (methods used in the past were often unsuccessful).

Other important developments are the construction of high-head navigation locks on soft soil, the erection of powerhouses under similar

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conditions, the construction of large pumping stations and irrigation systems, etc.

Increased demands have been placed on Soviet power-equipment construction: the creation of new large hydraulic turbines and the improvement of associated equipment.

Thanks to the efforts of Soviet scientists and engineers, power-construction techniques were brought up to world level; problems never attacked abroad have been solved in the USSR.

It has become standard practice to build large hydro developments relatively quickly, despite some of the most difficult hydrologic and topographical conditions. Large programs have been carried out to obtain most accurate values for design data on hydraulic loading, seepage, the behavior of sand and clay soils, and submerged structures built on pervious soil.

In line with the policy of the Soviet government to widen the role of science in hydropower construction, the number of scientific research agencies and institutes of higher education has been considerably increased. Hydraulic-engineering institutes which, before the revolution graduated only 150-200 specialists, are now producing thousands of specialists in hydraulic engineering and applied hydrology every year.

Scientific research is divided into theoretical studies, laboratory work, and field tests on structures — both operating and under construction. This division of the work has proved extremely successful.

Experimental facilities for hydropower research have increased considerably in scope. Not long ago, model testing of hydrotechnical structures was practiced only on a very small scale. Today almost every hydraulic laboratory has a model-testing unit, and not a single hydrotechnical structure is completed without model tests. Model testing is today deeply involved in design, and the collaboration of scientist and practical engineer is common in power construction. In the Soviet Union tens of hydraulic, hydrotechnical, and similar laboratories are functioning at scientific-research institutes, institutes of higher learning, plants, and even on construction sites.

Research has been carried out at the construction site of Gorkovskaya HEP on the effect of temperature variations on thin water-retaining slabs; on temperature conditions in the buttress dams at the Yaniskoski construction site; the effect of electric heating on concrete (the Kuibyshev hydro development site); the behavior of rock foundations (Charvak Dam), etc.

Similar research work has also been carried out on the construction sites of the Volkhovskaya, Dnieper, and Svirskaya hydropower plants, the Volga-Moskva Canal, etc.

Some of the achievements of Soviet scientists and engineers are the following:

1. A new theory of earth and concrete dams, which permits the construction of large dams under very difficult geological conditions, and cuts down the work and material required.

2. The reduction of the length of water-retaining structures (dams) by using the powerhouse for idle discharge.

3. The construction of built-in powerhouses located within the spillway dam, thus making special spillway sections unnecessary, and reducing the amount of concrete needed.

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We would also like to mention the work of Soviet scientists in the field of hydraulics and hydrology: silt loading in natural and artificial channels; new theories on the transport of river load; streamflow conditions; river-channel deformation; construction of stable canals; the silting up of storage-lakes; the streamflow connection between the headwater and tailwater of water-retaining structures; nonuniform and unsteady flow in canals and channels; water hammer; seepage beneath the foundations of dams and cofferdams, and in canals and drainage systems; and seepage in coarse-grained materials, in rock-fill, and in nonhomogeneous soil. Research work carried out in related fields is also important: the theory of elasticity as applied to structures; the theory of structures and building materials; and engineering geology.

Important successes were also obtained in the [relatively] new subject of soil mechanics. The rapid progress of this branch is a result of the use of mathematical methods, and the application of the latest advances in physics, chemistry, engineering geology, soil science, etc. Soil mechanics permits a deeper insight into the origin and formation of soils and other ground materials, and into the processes that occur in soil as a result of the construction of various hydrotechnical structures. The achievements of soil mechanics have made it possible to solve problems of controlling the behavior of soil in hydrotechnical structures; this refers both to soil underlying such structures, and to its use as a building material.

A great deal of research work was carried out on the construction site of Nizhne-Svirskaya HEP im. Graftio. This work involved the sinking of 200 bore holes, with a total length of more than 6000 m, and the driving of shafts with diameters of up to 5 m, to a depth of 30 m. More than 800 soil tests were made, and 150 holes were drilled for piezometric tests (some of them to a depth of 25 m). Deformation of structures was studied at 260 control points.

Successes were also obtained in the field of static stability for various hydrotechnical structures (earth and concrete dams, tunnels, and pipelines), in the design of new equipment, and in the devising of new construction methods. Many of these methods were unknown abroad.

Thus, in the field of large-scale hydromechanization, Soviet engineers developed new methods for the hydraulic filling of coreless dams, methods of unilateral, bilateral, and mosaic filling, and filling methods adapted to severe climatic conditions. These extremely effective methods were successfully applied in the construction of the Ivankovo, Tsimlyansk, Volga, and other developments.

Much attention was paid to the general problems of power engineering: extra-high-voltage transmission lines over long distances, interconnection of power systems, improvement of electric equipment, automation and controls, etc.

Research work in power engineering gave rise to a flood of scientific literature: handbooks and textbooks on hydrotechnical structures and numerous monographs and papers in periodicals. Many foreign scientists and engineers, on reading in Soviet publications of the successes obtained in power construction in the USSR, praised these achievements[2].

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HYDROLOGY AND HYDRAULICS. STORAGE RESERVOIRS

No hydrotechnical structure can be built without a knowledge of the hydrologic regime of the water body on which it is to be erected. In the early days of power construction, hydrology was taken into account only empirically. It was only when the progress in hydrology established it as an independent science, that this discipline began to be applied to hydrotechnical construction.

In the second half of the last century, with the development of navigation in Russia, the study of Russian waterways was started. Particular attention was given to river-runoff problems. The necessity arose of making calculations for bridges and conduits, for peak water discharge at railroad and highway crossings. The first attempt at an analysis of rainfall runoff dates back to 1897, and appears in a paper published by F.G. Zbrozhek[3]. Snow-melt runoff was studied by A. Karachevskii-Volk.

These and many other studies started a new period of development in the theory of streamflow and runoff.

The development of water management in the USSR, initiated by the GOELRO Plan and continued as a result of subsequent plans for economic expansion, posed many serious problems to hydrologists, particularly in utilization and control of runoff. The erection of various hydrotechnical works in the USSR made obvious the pressing need for knowledge of the characteristics of the runoff of a large number of rivers, and for the ability to make long- and short-range forecasts of hydrologic phenomena. Unfortunately, it was not possible to obtain clear answers to these problems because of the lack of development in hydrology.

This backwardness in theoretical hydrology was shortlived; it was overcome by the work of many scientists, among them D.I. Kocherin. In his study, "Mean long-time, monthly, and annual runoff in the European territory of the USSR", published at the end of the twenties, he wrote, "We must recognize that a serious discrepancy exists between hydro construction [as practiced] and hydrology".

The merit of his work lies in the fact that he was the first to develop unorthodox concepts of channel flow, trying to systematize knowledge of channel processes on a territorial basis, linking them with natural factors and with man's economic activity. He was the first to stress the geophysical aspects of runoff distribution, and its seasonal characteristics. Kocherin also studied the variation in annual runoff, and showed this variation to be a function of the area and topography of watersheds. He also studied in detail the maximum and minimum runoff of Soviet rivers and developed formulas which he used in working out the hydrologic zoning of the USSR.

In his runoff investigations, Kocherin was the first to use the water-balance method, which subsequently became standard practice in hydrologic calculations.

Kocherin was frequently consulted in the design of hydropower projects, often being the sole person from whom relevant hydrologic data was obtainable.

Soviet scientists made important contributions to the development of hydrology and its various branches, particularly in connection with the theory of streamflow and runoff, periodic and seasonal fluctuations of runoff, and the forecasting of hydrologic phenomena.

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Many publications appeared containing calculation methods applicable to water-management problems. In 1933, the first comprehensive book on runoff control appeared: Potapov, M.V., Regulirovanie stoka (Runoff Control), Moskva. 1933. 2nd edition. 1940.

Soviet scientists have applied with particular success the methods of hydrologic forecasting to the prediction of runoff for hydropower stations, storage lakes, and other water systems.

Much attention has been paid to problems of river-channel dynamics, and Soviet research has been of basic importance in the design of various river- and sea-management projects (in the calculation of erosion, silt transport, the silting up of storage lakes, etc.).

The theory of river-channel processes was greatly advanced by the nineteenth-century Russian scientists V.M. Lokhtin and N.S. Lelyavskii. Lokhtin was the first to understand the effect of the transport of river load, and to establish a relationship between this load transport and channel-bed deformation. Lelyavskii was the first to explain the form of river channels by measuring the surface and bottom flow lines of the stream. In the light of his investigations, it became possible to treat mathematically the mechanism of river-load formation and transport, and thus to understand the process of channel formation.

The climatic conditions peculiar to the USSR make the study of the winter regime of rivers and artificial channels and canals of great importance in the design of hydrotechnical structures. Soviet scientists are much ahead of foreign workers in this field. Scientists such as Academician N.N. Pavlovskii and Professor V.Ya. Al'tberg have drawn a scientifically well-founded picture of the winter thermal and ice regime of rivers and other water bodies situated in the area of hydro developments. Their studies are now used as a basis for the standard methods of calculating streamflow beneath an ice cover, and underlie the reliable forecasting of the thermal regime for various water-management projects.

Storage lakes. Hydrotechnical structures erected on a river site create a storage lake (reservoir) which is an important streamflow regulator. Some of the largest Soviet rivers, the Volga, Kama, Dnieper, Don, Ob, Angara, etc., are, in the course of time, turning into a chain of storage lakes, interconnected by deep waterways. Storage lakes transform the streamflow, adapting it to the needs of power generation and other water-management projects. The Rybinsk storage lake, downstream from the confluence of the Sheksna and Volga, has a volume of 25 billion m^3 of water. A four-meter depth of the lake represents a useful capacity of 16 km^3, or 35% of the annual runoff of the upper Volga. Before the construction of this lake, the level of the Volga near the town of Yaroslavl rose, during the high-water season, by 8-10 m. Since the construction of the lake, seasonal variations of the level do not exceed 2-3 m. Further, during the low-water season, the level of the Volga is 1.5-2 m higher, and the rapids on the rivers Mologa and Sheksna are now submerged.

Storage lakes reach huge dimensions (Figure 49)[4]. The useful capacities of these lakes are measured in billions of cubic meters and their areas in square kilometers. They often extend hundreds of kilometers. During storms, the waves on such lakes reach a height of up to 5 m, and it is not surprising that these lakes are called artificial "seas".

The first large storage reservoir in the USSR, the Dnieper Lake, or as it is called, "Lake Lenin", formed thirty years ago in connection with

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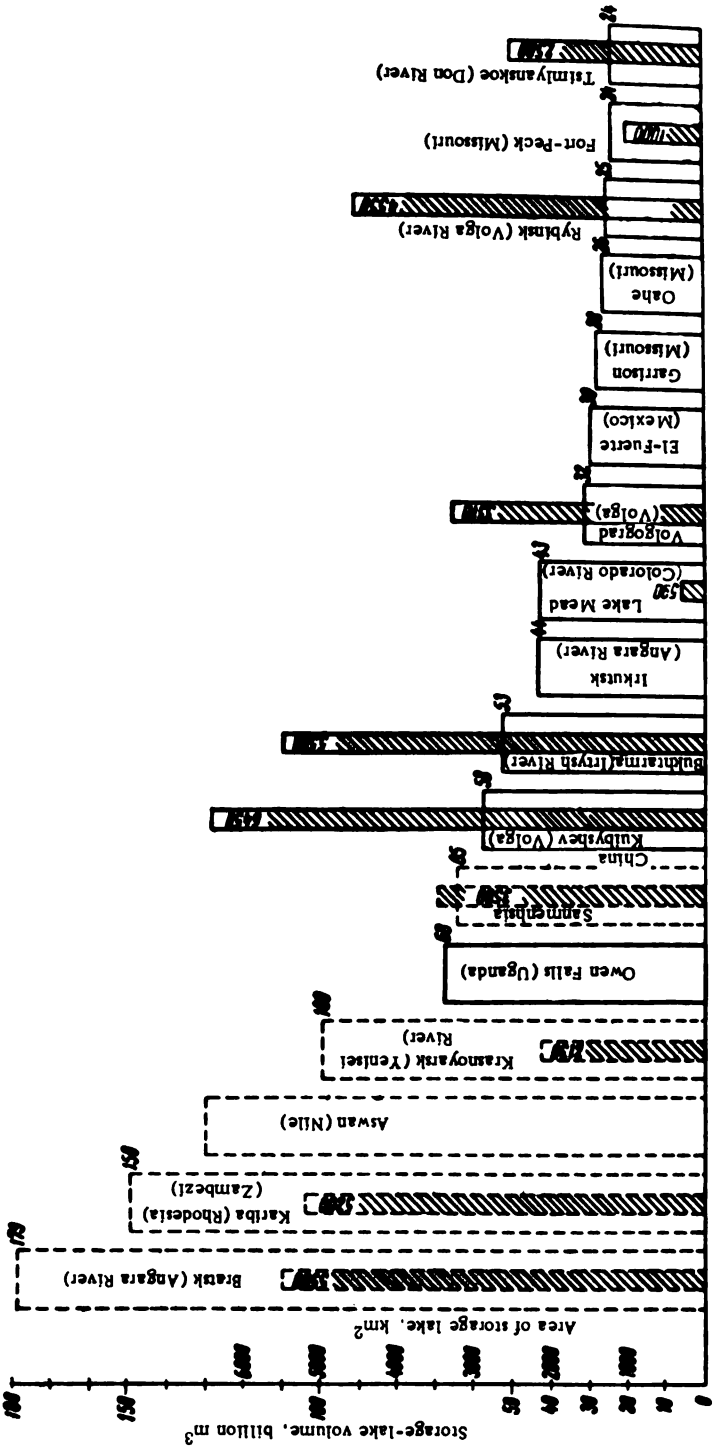

FIGURE 49. Some of the world's largest dams
(The crosshatched area indicates the area of the lake)

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the building of the Dnieper Hydroelectric Plant. The Ivankovo storage lake (also known as the "Moscow Sea") was filled in 1938 and constitutes an integral part of the Volga-Moskva canal system. The early lakes were of modest size, but the Rybinsk storage lake, which made its appearance on the map of the USSR only three years later is very large: it is half the size of Lake Onega, Europe's second largest natural lake. Large lakes are no longer a rarity in the Soviet Union, e.g., the Kuibyshev Lake (the Zhiguli Sea) which extends over more than 500 km, and has a volume of 58 billion m^3.

The Bratsk storage lake started to fill in 1961. With an area of 5500 km^2 and a volume of 179 km^3, it will be the largest artificial reservoir in the world. The lake will contain two years' runoff of the Angara River, thus ensuring a uniform level of power generation.

There are more than 20 large storage lakes in the USSR, some already in use and others under construction (Figure 50). There are also many smaller lakes and ponds (Table 24). The total area of these lakes is about 50,000 km^2; their total volume is 400 billion m^3.

Hydraulics has always been given much attention by Russian and Soviet scientists, among them Lomonosov, Mendeleev, and Joukowski, and later (after the establishment of the Soviet regime) Chaplygin, Pavlovskii, and Zamarin. The scientific work of these scientists has had a great influence on the development of hydraulics and its practical application.

Joukowski established hydromechanics as a separate scientific discipline; this helped in the further development of hydraulics and hydraulic engineering.

The classical studies of N.N. Pavlovskii were of the utmost importance in the development of hydro engineering. They are still the principal textbooks for hydraulic engineers, not only in the USSR. Every Soviet book dealing with hydrotechnical problems contains quotations from these classics of Russian science.

Pavlovskii devoted his attention to the fundamental branches of hydraulics and hydromechanics: flow of artesian water, ground-waterflow, flow in open channels, and the hydraulics of structures. Chaplygin, in his study on Pavlovskii wrote: "In all his investigations, Pavlovskii exhibited uncommon clarity of thought, and a particular gift for finding the correct explanation of phenomena investigated"[5]. Pavlovskii studied and explained the most important aspects of ground-water flow: he is the author of the hydromechanical theory of underground filtration and seepage. In developing his theoretical concepts, and establishing the basis for the practical application of the method of "electrohydrodynamic analogy" (EHDA)[6], he also developed the following:

a) A method for calculating the necessary thickness of bottom structures for hydrotechnical works.

b) The solution to the problem of the so-called "filtration forces", which act in the pervious foundations of hydrotechnical structures.

c) Approximate methods of calculating ground-water flow beneath structures. This method has been called the "technique of fragments", it has sufficient accuracy for practical applications.

d) The solution of the problem of seepage in anistotropic stratified ground, underlying hydrotechnical structures.

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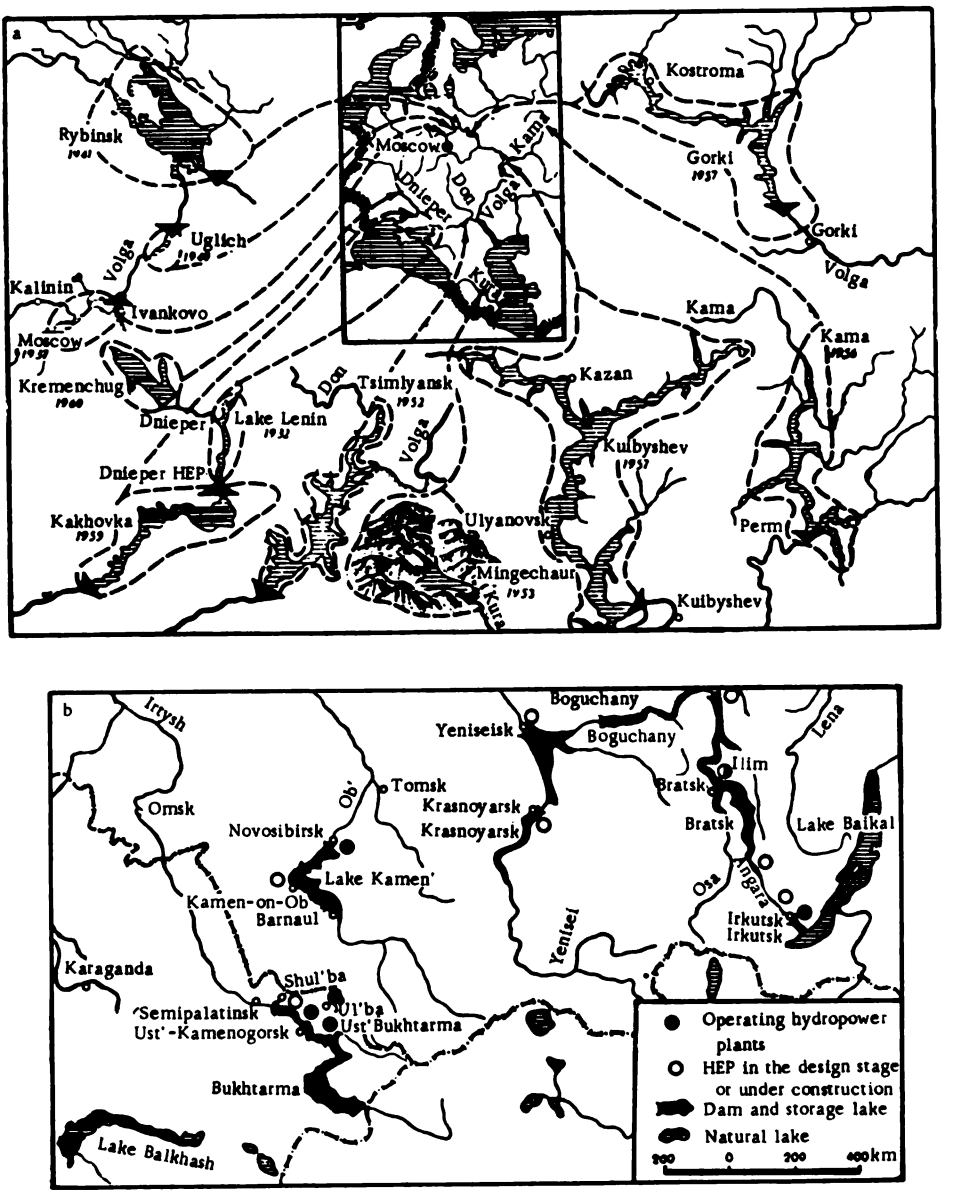

FIGURE 50. Artificial "seas" of the USSR

a — European USSR; b — Asian USSR.

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TABLE 24

Largest storage lakes of the world

Name, year of completion, country, river	Purpose*	Volume, billion, m^3		Area, km^2	Length	Remarks Type of dam and overall dimensions**
		total	useful		Width, km	
1	2	3	4	5	6	7
Bratsk, 1965, USSR, Angara	PN	179	50	5500	650 / 25	Filling started 1 Sept., 1961
Kariba, 1960, Southern Rhodesia, Zambezi	P	150	25	5200	280 / —	Arch-gravtiy dam, H = 125; L = 615; V = 2.0; 2 power plants; 2000 Mw; 7 bill. kwhr/yr; 1st stage 600 Mw, 93 m head
Aswan (Sadd el Aali) 1967, UAR, Nile	PCI	130	100	—	500 / —	Rock-fill dam, H = 111, L = 5000, V = 42; 2100 Mw; 10 bill. kwhr/yr 1st stage 800 Mw
Krasnoyarsk, 1966, USSR, Yenisei	PN	73	30	2130	380 / 15	Filling to start in 1965
Owen Falls, 1953, Uganda, White Nile	P	68	—	—	—	Lake Victoria level raised by 1.2 m
Sanmenhsia, 1962, CPR†, Hwang Ho	PCI	65	—	3500	—	Gravity dam: H = 90 m; V = 2; 1100 Mw
Kuibyshev (Zhiguli Sea) 1957, USSR, Volga	PINC	58	34.6	6450	600 / 40	Filling of storage lake Nov., 1955 to 11 June, 1957
Kamenskoe (design stage) USSR, Ob	PCIN	54	27	4500	70 / —	Dam will create a head of 25 m
Bukhtarma (Irtysh Sea), 1961, USSR, Irtysh	PNC	53	31	5500	600 / —	Concrete dam; H = 90 m; filling of reservoir started spring 1960; the level of the reservoir reached that of Lake Zaisan in Oct., 1960; V = 25 bill. m^3
Tankiangkow, 1962, CPR, confluence of the Tan and Han rivers	PC	51.6	—	—	—	Concrete dam; H = 130; V_{con} = = 3; 900 Mw
Lower-Kama (design stage), USSR, Kama	PCN	45.6	26.1	5400	—	1400 Mw
Irkutsk, 1957, USSR, Angara	PNW	46	—	244	—	Raised the level of Lake Baikal by 1 m
Lake Mead (Boulder) 1941, U.S.A., Colorado	PICW	43.7	—	590	185 / 13	Arch-gravity dam, H = 222, L = 390 m; V = 2.5
Shul'ba (design stage) USSR, Irtysh	P	37	—	—	—	

* I = irrigation; C = runoff control; N = navigation; P = power, W = water supply.

** H = height, m; L = length, m; V = volume, million m^3

† [Chinese People's Republic.]

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TABLE 24 (cont'd)

1	2	3	4	5	6	7
Sunda, 1961, Central Congo	P	35	—	1600	270 / —	Arch dam, H = 125; L = 250; 800 Mw; head = 101.5 m
Glen Canyon, 1963, U.S.A., Colorado	PI	34.4	—	—	300 / —	Arch-gravity dam, H = 177; L = = 458; V = 3.6; 900 Mw
Volga HEP im. XXII Congress of the CPSU, 1960, USSR, Volga	PIN	32.1	8.65	3310	670 / 14	After completion of Saratov HEP, the forebay area will be reduced by 190 km^2, the gross volume by 0.67 km^3, and the useful volume by 0.40 km^3
El Fuerte, 1940, Mexico, Fuerte	I	30	—	—	—	Gravity dam, H = 90
Garrison, 1956, U.S.A., Missouri	CNIP	28.4	16.7	1580	322 / 22.5	Earthfill dam; H = 64; L = 3600; V = 53.5
Oahe, 1963, U.S.A. Missouri	CNIP	28.2	17.0	—	—	Earthfill dam; H = 74; V = 69
Rybinsk, 1941, USSR, Volga	PCNW	25.4	11.7	4550	140 / 80	Core filled with river sand; level of Volga raised by 16 m
Cheboksary (design stage) USSR, Volga	PCN	24.8	15.6	3780	—	1400 Mw
Fort Peck, 1939, U.S.A., Missouri	CINP	24.0	13.8	1000	225 / 25	Earthfill dam; H = 76.2; L = 2740; V = 95.5; largest earthfill dam in the world
Tsimlyansk, 1952, USSR, Don	PINC	23.8	11.5	2700	360 / 38	Earthfill dam; H = 40; L = 12,800; V = 33.2
Ramapadasagar, 1961, India, Giodavari	PI	20	—	—	—	Concrete gravity dam; H = 130; V = 7.5
Tres Marias, 1961, Brazil, San Francisco	PI	20	—	1000	—	Composite dam; H = 64; L = 2700; 480 Mw
Kakhovka, 1955, Ukrainian SSR, Dnieper	PNIW	18.2	6.8	2155	234 / 40	Run-of-river earthfill dam; H = 30; L = 1200; V = 7
Sinan Kiang, 1961, CPR, Sinan River	PCN	17.8	—	580	—	Concrete gravity dam; H = 106; L = 435; 580 Mw
Mingechaur, 1953, USSR, Kura	CPIN	16.0	7.4	630	70 / 13	Earthfill dam; H = 87; first large Soviet earth dam
Saratov, 1965, USSR Volga	PNI	15.4	=	1950	350	Dam of preassembled units; constant-level storage lake; uses water discharged from Volga HEP im. Lenin upstream

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TABLE 24 (cont'd)

1	2	3	4	5	6	7
Rincon del Bonete, 1943, Uruguay, Rio Negro	CPN	15	6.6	1400	140 / —	Concrete dam; H = 36; L = 1170; V = 0.26; dam includes a 415 m buttressed section
Kremenchug, 1960, Ukrainian SSR, Dnieper	PCN	13.5	9.0	2500	250 / 50	More than 70% of power potential developed in this section of the Dnieper
Alvaro-Obregon, 1953, Mexico, Yugui	I	13.4	—	—	—	Earth dam, H = 56
Supung, 1946, Korea, Amnok-kang	P	12.0	—	180	—	Concrete dam; H = 107; L = 900; 700 Mw
Grand Coulee, 1941, U.S.A., Columbia	PCI	11.8	6.4	322	242 / —	Concrete gravity dam; H = 169; L = 1280; V = 7.8; largest dam in the world in terms of concrete volume
Nagarjuna-Sagar; 1963, India, Kistna	I	11.5	—	285	—	Gravity dam; masonry and concrete; H = 91, V = 5.2
Suapiti, 1960, Guinea (Africa), Konkoure	PI	11.0	—	—	—	Earth dam, H = 120; L = 1070; V = 25; underground powerhouse; 500 Mw
Perm, 1956, USSR, Kama	PNW	10.7	6.7	1720	300 / 35	Concrete spillway dam; H = 36; L = 400; powerhouse built into spillway dam
Nurek, 1965, Tadzhik SSR, Vakhsh	PCIN	10.5	4.5	98	80 / 40	Rock-fill dam; H = 291; V = 45
Fengman, 1956, CPR, Sungari	PNC	10.0	—	—	170	Concrete dam; H = 80; L = 1000; V = 2
Votkinsk, 1962, USSR, Kama	PNC	9.7	2.0	1120	370 / —	
Bhakra, 1962, India, Sutlej, tributary of the Indus	PIC	9.25	7.0	170	—	Gravity dam, H = 208; L = 512; V = 3.9; 900 Mw
Novosibirsk ("Ob Sea"), 1960, USSR, Ob	PNCW	8.8	4.4	1070	200 / 40	
Gorki, 1957, USSR, Volga	PNC	8.7	2.8	1570	400 / 20	Total length of water-retaining structures 16,300 m
Sakarya, 1954, Turkey Sakarya	I	8.4	—	—	—	Gravity dam, H = 108
Hirakud, 1957, India, Mahanadi	IP	8.14	5.8	710	—	Gravity, concrete and masonry dam; H = 50; L = 2500; V = 1.11

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TABLE 24 (cont'd)

1	2	3	4	5	6	7
Ford Randall, 1954, U.S.A., Missouri	CNIP	7.8	2.96	—	—	Earth dam, H = 49; L = 3000, V = 38.4
Hirfanli, 1960, Turkey, Kizil Irmak	PI	7.65	=	280	75/15	Earthfill dam; H = 82; L = 365; V = 2.3; 128 Mw
Wolf Creek, 1952, U.S.A., Cumberland	P	7.5	=	255	160/—	Gravity dam; H = 78.7; L = 1750; 270 Mw
Kentucky, 1944, U.S.A., Tennessee	NCP	7.4	4.95	1030	297/4.8	5 billion m^3 capacity; for flood storage; concrete dam; H = 63; L = 2570
Denison, 1945, U.S.A., Red River	P	7.24	—	—	—	Earth dam; H = 50.4; L = 534; 176 Mw
Little Zab, 1961, Iraq, Little Zab and Tigris	IPC	6.8	—	—	—	Arch dam; H = 116.5; L = 350; V = 0.380
Bull Shoals, 1953, U.S.A., White River	I	6.6	—	290	—	Concrete gravity dam; H = 87; L = 688; V = 1.6
Shasta, 1944, U.S.A., Sacramento	CIP	5.6	5.3	120	56/—	Concrete dam; H = 171; L = 1070; V = 5.0; 379 Mw
Passe Dangereuse, 1943, Peribonca	P	5.5	—	320	—	Storage lake of Shipshaw No. 2 HEP; erected in severe arctic conditions; concrete dam; H = 48; L = 360; V = 0.100
Gatan, 1912, Panama Canal, Chagres	CPN	5.2	—	425	47/—	Semi-earthfill dry-filled dam; H = 35; L = 2540; V = 17.5
Sharavati, 1958, India, Sharavati	IP	5.0	—	—	—	Concrete dam, H = 58; L = 2350; 861 Mw
Aswan, 1933, Egypt, Nile	INP	5.0	—	—	—	Massive concrete dam, 1902, created a storage lake which by volume (1 billion m^3) was, until 1911, the world's largest reservoir. In 1913, height of the dam was raised and the capacity of the lake was brought to 1.5 billion m^3. In 1933, after another increase in height, the capacity reached 5 billion m^3. Dam dimensions: H = 53; L = 2120; V = 1.32 (masonry)
Miyun 1961, CPR, confluence of the Chao and Pai rivers	CPIW	5.0	—	—	—	—
Liukiahsia, 1963, CPR, Hwang Ho	PINC	5.0	—	—	—	Arch-gravity dam, H = 120; 1500 Mw

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TABLE 24 (cont'd)

1	2	3	4	5	6	7
Falcon, 1954, U.S.A.-Mexico, Rio Grande	I	4.9	—	—	—	Earth dam, H = 45
Hungry Horse, 1954, U.S.A., Flathead (Columbia River Basin)	IP	4.32	1.2	—	—	Arch dam, H = 174; L = 645; V = 2.3
Ross, 1952, U.S.A., Skagit	CP	4.2	—	—	—	Arch-gravity dam; H = 165; L = 396
"Tadzhik Sea" on the Syr Darya, 1957, USSR	IPC	4.16	2.6	450	60/20	Kairakum HEP spillway dam
Cardenas, 1948, Mexico Nazas	I	3.9	—	—	—	Earth dam; H = 90.5
Peixoto, 1957, Brazil, Rio Grande	I	3.9	—	—	—	Concrete gravity dam; H = 60
Tungabhadra, 1954, India, Tungabhadra	IP	3.7	—	—	—	Masonry dam; H = 49; V = 0.920; 139 Mw
Mettur, 1934, India, Cauvery	IP	3.65	—	—	—	Concrete-gravity dam; H = 67; L = 1500; V = 1.5
John Ch. Carr (Baggs Is.), 1952, U.S.A., Roanoke	PI	3.6	—	—	—	Concrete-gravity dam; H = 44, L = 840; 204 Mw
Table Rock, 1958, U.S.A., White River	PI	3.36	—	—	—	Concrete-gravity dam; H = 83; earth dam; V = 1.46
Lake Lenin [Dnieper HEP], 1932, Ukrainian SSR, Dnieper	PNI	3.3	1.42	410	90/—	Zaporozhe concrete dam; H = 62; reconstructed in 1947
Elephant Butte, 1916, U.S.A., Rio Grande	I	3.3	—	160	65/—	Concrete dam; H = 94; L = 355; V = 0.46
Norris, 1936, U.S.A., Clinch	CP	3.2	2.8	138	116/1.9	Concrete dam; H = 80; L = 560; V = 765
Saluda, 1930, U.S.A., Saluda	P	2.84	—	200	67/—	Semi-earthfill dam; H = 63; L = 2300; V = 8.4
Boquilla, 1915, Mexico, Rio Conchos	I	2.8	—	—	—	Gravity dam; H = 80; V = 0.3
Bagnell, 1931, U.S.A., Osage	P	2.5	—	245	200/—	Concrete gravity dam; H = 45; L = 775; V = 0.422
Center Hill, 1953, U.S.A., Cumberland	PI	2.5	—	94	102/—	Composite concrete-earth dam; H = 76.5; L = 660; 135 Mw
Martin (Cherokee Bluff) 1928, U.S.A., Tallapoosa	P	2.5	—	250	—/30	Concrete dam; H = 60; L = 600; 135 Mw.

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TABLE 24 (cont'd)

1	2	3	4	5	6	7
Bab'egorodskoe, 1835, Moscow, Moskva River	CN	2.5	—	—	—	Bab'egorodsaya Dam, built to a design of Palubin and Bugaiskii (engineers) with cast-iron foundation girders laid on the apron
Merid Lake, 18th century B.C., Bahr Yusuf channel of the Nile	IN	2.8	—	2000	—	Maximum depth of lake 89 m; remains of lake to be found near Faiyum (depth of lake still 3 m)

e) The solution of the problem of seepage at the base of rock-fill dams.

In the field of (free) ground-water flow, Soviet scientists developed a hydraulic theory which permits accurate solution of many practical problems connected with unsteady seepage flow (under conditions of laminar and turbulent flow). Pavlovskii also worked out a very useful method for calculating seepage beneath earth dams and canal beds.

Soviet scientists have made various contributions to the theory of open-channel flow: improvements in the use of Chezy's formula; calculation methods for treating streamflow in channels with nonuniform roughness; method for plotting the curve of the free surface of a streamflow which has nonuniform motion; a novel calculation method for treating nonuniform flow in canals; analytic and graphic methods for plotting the curve of the free surface of natural water courses; and a calculation method for treating streamflow beneath an ice cover.

In the field of the hydraulics of structures, Soviet scientists have suggested a solution of the problem of the plane (undimensional) stream junction between headwater and tailwater sections. A novel method for making calculations on the operation of dam-gates has been developed, methods for treating the streamflow in chutes have been elaborated, a general formula for spillways has been found, etc.

In the USSR, the hydraulics of structures is investigated in more than forty laboratories located in scientific-research institutes, etc. The level of Soviet theoretical and experimental work in this subject is now the highest in the world. Particular mention should be made of the outstanding results obtained in developing calculation methods for treating overfalls, chutes, spillways, etc. The work on the theory of seepage flow beneath hydrotechnical structures should also be mentioned. This problem was thoroughly investigated as far back as 1922, when Pavlovskii wrote his study: "Teoriya dvizheniya gruntovykh vod pod gidrotekhnicheskimi sooruzheniyami i ee osnovnye prilozheniya" (Theory and Main Features of Ground-water Flow beneath Hydrotechnical Structures). This theory was further developed in some of Pavlovskii's later studies, and in the work of E.A. Zamarin, etc.

Soviet scientists also worked out a hydromechanical method of treating nonoverflow earth dams, cofferdams, dikes, by-pass seepage, seepage in coarse-grained and nonhomogeneous soil, and in fissured-rock formations.

These investigations shed new light on the complex phenomena of seepage in the area of water-retaining structures, and serve as a basis

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for the development of model-testing methods of investigating the phenomena, and for improving the design of hydrotechnical structures erected under various geological and hydrologic conditions.

Pavlovskii's method of calculating ground-water flow, advanced as early as 1922, is based on the electrohydrodynamic analogy (EHDA), and has found wide acceptance both in the USSR and abroad. This method, which can be applied to problems that do not admit a direct mathematical treatment, permits the model testing of seepage flow to be carried out with high accuracy (0.1-0.2%), and is thus indispensable in hydroengineering work.

Other experimental techniques developed by Soviet scientists are also widely used. Thus the "slot flume" method developed by E.A. Zamarin may be used in problems connected with unsteady seepage flow.

The investigations into seepage phenomena made it possible to design correctly the submerged elements for hydroengineering projects and to erect large rock- and earthfill dams even on the pervious soil associated with many Soviet lowland rivers. Many foreign specialists had previously regarded these soils as unsuitable for supporting dams.

Much attention is being paid to the hydraulics of the tailwater sections of dams and other hydrotechnical structures. The water spilling over the dam crest has enormous kinetic energy; at Tsimlyanskaya Dam the nappe acquires 9000-10,000 kw. Such a flow can erode a tailwater structure to a depth of tens of meters, thus endangering the safety of both the dam and the associated structures. At Volkhov HEP, the nappe caused erosion of the limestone base to a depth of 2 m. In the tailwater section of Farkhad Dam erosion of the rocky bed reached a depth of more than 10 m in five years of operation. Means for dissipating the kinetic energy of the nappe are therefore of great importance.

Soviet scientists developed new calculation methods for treating the hydraulic dispersal of the spilling water, and successfully designed new energy-dissipating elements: chute blocks at Svir HEP, toothed sills for the dams of the Volga-Moskva Canal, and dissipators of ski-jump, fan, and rail-type.

At Volkhov HEP, the problem of efficient energy dissipation was successfully solved by using a submerged hydraulic jump.

The question of efficient energy dissipation is intimately connected with the correct operation of gates and the design of the tailwater structures. Thus, inclined aprons directly adjoining the spillway and sloping gently toward the river channel are being increasingly used in practice. A novel trend is to cover the apron with concrete slabs arranged in a roof-tile pattern. The streamflow over such slabs, which have an inverted slope, creates additional hydrodynamic pressure, thus increasing the stability of the apron. Our knowledge of the hydraulics of tailwater sections now permits us to predict the behavior of a river channel after its damming up. It is now possible to design hydrotechnical structures to withstand a free-falling jet of water.

Another problem which has received particular attention in Soviet research is the action of waves on hydrotechnical structures, and on the banks of storage lakes. This is understandable since many large hydro-developments have huge storage lakes, exposed to the action of wind-driven and roll waves. These problems have been successfully solved both in their theoretical and experimental aspects.

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On the basis of the research results, practical rules have been developed for the design of protective structures for river and reservoir embankments, and for other purposes.

HYDROTECHNICAL STRUCTURES

The great diversity of natural conditions in the USSR determines the character of the hydrotechnical structures erected. The factors referred to are the predominance of lowland territories, the large flood plains, the sandy and clayey subsoils, the frequent occurrence of floods, and the severe climate.

Foreign practice has been to construct dams mainly on rocky foundations. In lowland areas with sandy or clayey soil, spillway dams for large heads were normally not erected. In such areas the head of the dam is usually kept down to a few meters, and the dam cannot be used for runoff control or power generation; its function is to increase navigation depth or to permit water intake for supply purposes.

The Soviet hydropower designer is faced by many complicated problems, of both an economic and technical nature. In the lowland areas of the European Territory of the USSR many rivers flow through sandy and sand-clay soil. Two alternatives exist: to adopt foreign practice, i.e., to avoid building high-head dams on such rivers, or to erect dams for heads of up to 20-30 m and harness the water-rich lowland rivers.

There are many difficulties in the construction of dams on soft soil. These difficulties stem from the reduced load-carrying capacity and shearing strength of such soils, and to their lower imperviousness.

At a conference held at the Gidroelektroproekt Institute on 15 November, 1931 Professor Omodeo, the well-known Italian specialist in water management and hydraulics who has been invited to the USSR for consultations, said: "The basic problem in such structures is the dam ... As is known, the channel of the Volga consists almost entirely of fine-grain quartz sand containing almost no clay. Judging from experience, such a soil permits the erection of a dam for a head of 10-12 m. However, only very few such dams have been constructed and these were built under simpler conditions than those existing in the Volga Area. There has even been an instance of such a dam being carried away by the water, a few months after its construction ...

"For spillway dams on sandy ground, the limiting head is 10-12 m. Only a restriction to this maximum head can ensure safe operation of the dam in exceptional circumstances. If suitable conditions are present, a dam for a head of up to 15 m can be considered safe on sandy soil"[7].

This opinion of a foreign expert makes clear the difficulties connected with the construction on the Volga of dams for higher heads.

Following thorough scientific investigation, Soviet hydropower technicians solved the problem of constructing dams on soft soil. Dams for heads of up to 30 m have been built. These include dams of conventional type and types unknown abroad.

It is interesting to mention here that during the construction of the Parker hydro development on the Colorado (U.S.A.) in the forties, American engineers decided to excavate to a depth of more than 80 m in

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order to avoid the building of a dam on alluvial soil. A dam of 22 m net head[8] was then erected. About the same time, Soviet engineers constructed large dams on soft ground on the Svir and the Upper Volga. The building of the still larger dam for Tsimlyanskaya HEP on find sand was another remarkable achievement of Soviet power engineering.

Many of the Soviet projects for dams on soft soil were of novel concept. The Lower-Svir spillway dam constructed in 1934 has a dam base of widened cross section (the so-called flattened-section profile) with extensive drainage and a strong apron to increase the shear strength of the dam. The apron was made of an impervious reinforced-concrete slab 40 cm thick, with the reinforcing set into the dam body. To ensure a flexible junction between the apron and the body of the dam, the joint was filled with reinforced asbestos cement, rather than cement grout. The dam had a maximum height of 22 m, a length of 220 m, and a natural settlement of 24 cm.

The application of soil mechanics to the design of hydrotechnical projects permitted the construction of dams on soft (compressible) clayey soil, and allowed the prediction of the amount of settlement of the structural elements. An example is the Svir development, in which use was made of the tilting of the structures during settlement. The result was a powerhouse of unprecendented design (see Figure 7, earlier in this text).

The "two-tier" dam of the Ivankovo hydro development[9] on the Volga is another example of a dam with a base of widened cross section. This dam was erected on morainic clay and creates a head of more than 20 m (Figure 10).

The dams of the Uglich and Rybinsk developments are recent examples of designs for use on morainic and permian clay. Both are for a head of up to 18 m. To reduce the length of the Rybinsk Dam, and to permit the convenient discharge of water during construction, the dam has no spillways, the water being discharged solely through sluiceways. To economize in concrete, cavities in the reinforced-concrete are earth filled. The sluiceways are designed for a discharge of up to 70 m^3/sec. The Gorki Dam, whose construction started in 1948, and the dam of Tsimlyanskaya HEP on the Don River (for a head of up to 26 m), were erected on soft soil (clay and fine sand), previously believed to be unsuitable as a base for water-retaining structures. The problems of building dams on sand were solved by S. Va. Zhuk and a team of specialists. Tsimlyanskaya Dam (Figure 51), although erected on sandy soil, withstands a head of 26.6 m and permits a spring discharge of 20,000 m^3/sec (specific discharge on the apron — 33.5 m^3/sec).

The dams for a series of other hydro developments (Kakhovka, Volga im. Lenin, and Volga im. XXII Congress of the CPSU) were erected under still more unfavorable conditions.

All of these dams have sufficient stability and suffer relatively little settlement. Thus, the settlement of the earthfill section of the Kakhovka Dam by the end of 1960 was only 935 mm against a predicted 990 mm; the settlement of the concrete spillway section was only 247 mm (against 330 mm).

However, the settlement of the adjoining sections of the dam was greater, and this necessitated the carrying out of difficult repairs.

Figure 52 shows a cross section through a large modern dam [Volga im. Lenin] for a head of 15-30 m erected on sandy or clayey soil.

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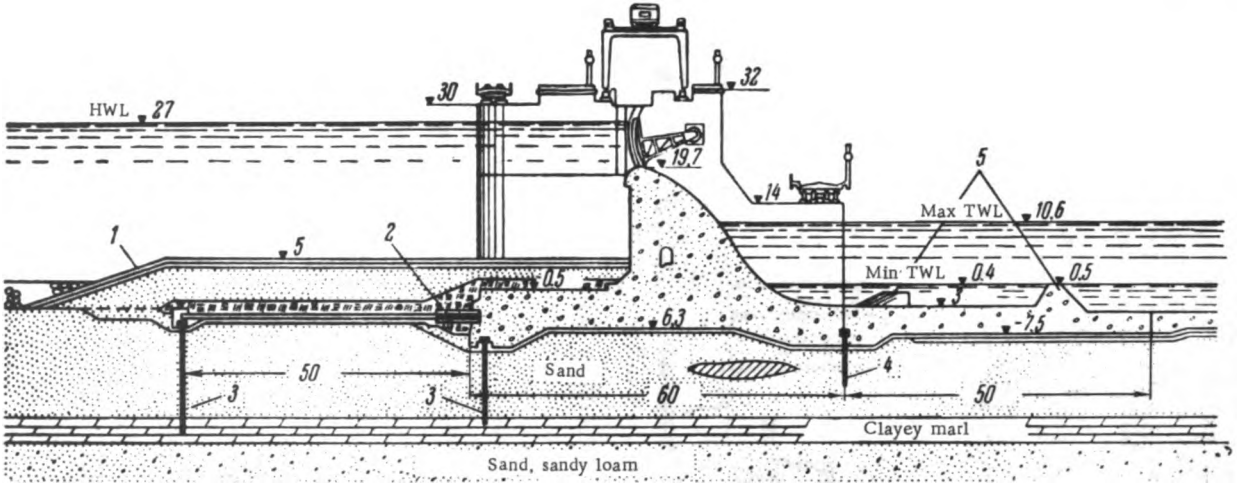

FIGURE 51. Cross section through the Tsimlyanskaya Spillway Dam

1 — concrete floor; 2 — flexible junction between apron and dam body; 3 — steel-sheet piling; 4 — perforated-sheet piling; 5 — stilling structure (chute blocks).

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The profile of this dam is similar to that of the Tsimlyanskaya Dam (Figure 51). The weight of the Volga Dam has been kept down by omitting concrete from the upstream face. An equivalent weight of water on the foundation plate and long apron compensates for the omitted concrete.

These dams, although erected on soft soil, have a relatively high discharge capacity. This permitted the spillway section to be kept short, thus keeping down the cost of the dam. Svir Dam, the first in the USSR to be erected on soft clayey soil, has a specific discharge on the apron of 16 m^3/sec. All the dams built later on clayey soil have a discharge of 50-56 m^3/sec.

Dams built on sandy ground, with suitable reinforcement of the tailwater apron, have specific discharges reaching in some cases 33-45 m^3/sec. The lack of experience in the construction of dams on soft soil made it necessary to carry out both laboratory and field research prior to drawing up designs.

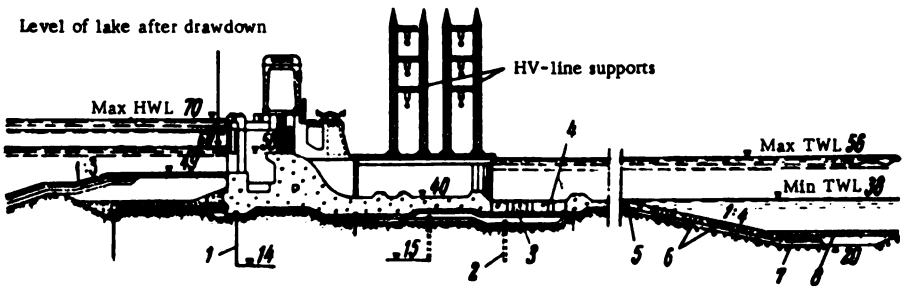

FIGURE 52. Spillway dam of the Volga HEP im. Lenin

1 — steel-sheet piling; 2 — deep-drainage holes; 3 — apron (reinforced-concrete slabs 0.15 m, concrete sublayer, 3.5 m rip-rap filling and three-layer inverted filter); 4 — drainage wells; 5 — downstream floor (10 × 10 × 1 m reinforced-concrete slabs, 0.1 m concrete sublayer, and 0.8 m thick inverted filter); 6 — drainage holes; 7 — reinforced-concrete cover (two layers of 0.25 m thick reinforced-concrete slabs 0.8 m thick, inverted filter); 8 — rip-rap bucket (rip-rap thickness 1.1-1.9 m, stone size up to 10 cm).

Kuibyshev Dam, Volga HEP im. Lenin, has the largest discharge capacity of all the large dams in the world (Table 25).

TABLE 25
Water discharge of some of the world's largest dams

Name of dam	Length, m	Head during flood discharge	Discharge, m^3/sec		Potential energy of nappe, Mw		Foundation
			total	per meter length	total	per meter length	
Volga im. Lenin (Kuibyshev	981	14.0	55,000	56	8,250	8.4	Sand
Dnieper im. Lenin	611	26.7	24,500	40	6,500	10.5	Granite
Tsimlyanskaya	500	16.0	22,400	45	3,600	7.2	Sand
Bonneville	275	6.0	45,000	165	2,700	10.0	Basalt
Kentucky	360	3.0	35,900	100	1,700	3.8	Sound rock

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For the design of hydrotechnical structures to be erected on soil underlain by rock salt, it was necessary to work out the mechanism of the seepage of liquids of differing densities (sweet water and brine). This permitted the prediction of the movement of salt in the foundations.

For the Perm HEP dam, located on ground with deep gypsum strata, the problem of stability was solved by arranging suitable drainage and seepage paths in front of the dam to avoid the leaching of the gypsum. This arrangement caused the seepage water below the dam base to become saturated with gypsum salt when it no longer endangered the integrity of the dam structures (Figure 59).

Until recently it was widely believed that dams could not be built in Karst regions. However the construction of dams in Bashkiria and Georgia disproved this (Figure 58).

Remarkable successes have been obtained in the construction of hydropower plants in permafrost regions (the Mamakan and Vilyui plants in the Lena River Basin).

Until the fifties, most Soviet dams and locks were of mass-concrete type, lightly- or normally-reinforced concrete being used. Light-weight dams (arch, buttresses, dome types) were only seldom erected[10]. This is understandable if we consider the conditions under which such hydrotechnical structures have to operate. Water has a mechanical, physicochemical, and biological action on these structures which have to be massive, possess adequate qualities of waterproofness, corrosion resistance, and resistance to silt and ice. High-strength concrete must be used in their construction.

The Zaporozh Dam of the Dnieper HEP im. Lenin is a typical example of a massive concrete [gravity] dam built on a rock foundation. For soft foundations, dams may be built with a broader profile, and with a coefficient of friction (0.14-0.46) (e.g., the dam of Lower Svir HEP). For massive dams the coefficient of friction is 0.6-0.7.

Soviet power construction has remarkable achievements to its credit in the design of concrete dams. Important refinements were developed in the theory and methods of static stability, hydraulic, and seepage calculations. New construction methods were introduced: preassembled concrete units, reinforced-concrete facing shells, vibration and vacuum treatment of concrete, etc.

Nevertheless, there are still a number of weak points in the design of massive concrete structures. Massive dams still contain a large volume of concrete which increases the effect of exothermic processes, resulting in greater seepage pressure in the masonry. Not having sufficient confidence in the quality of the concrete or the concrete placing, designers have often used a higher than normal safety factor for concrete work. This increased the consumption of concrete and steel reinforcing. In the Volga and Dnieper dams a few kilograms of steel reinforcing per cubic meter of concrete were used. In Lower-Svir Dam, erected on a gypsum foundation, 35 kg/m^3 were inserted. Later dams erected on soft ground had even higher levels of reinforcing (up to 50 kg/m^3). The reinforcing in the locks of the Tsimlyanskaya, Kakhovska, Gorki, and Volga hydro developments reached 70 kg/m^3 (cf. 32 kg/m^3 in the locks of the Volga-Moskva Canal).

The consumption of cement per cubic meter of concrete is also steadily increasing. Thus, in the structures of Volga HEP, 326 kg of cement were

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used per cubic meter of conrete; for Kakhovka HEP the figure was 329 kg/m^3 (cf. an average value of 225-275 kg/m^3 for large hydrotechnical structures. (In the U.S.A., the cement content of concrete is still lower). Only in the construction of Volga HEP im. XXII Congress of the CPSU were significantly lower cement-consumption figures recorded.

It became clear that urgent steps had to be taken to reduce the consumption of cement and concrete in massive structures by making bold use of light-weight and thin-walled dams, by increasing the use of precast elements, and by developing new dam designs.

Concrete of improved quality should be employed in gravity dams, and wider use should be made of stiff concrete and heterogeneous aggregate. The proper lining of upstream faces, and the appropriate use of concrete mixes of lower grades, will result in important savings in materials. In some instances, the cement content of concrete can be reduced to 230 kg/m^3. A way of increasing the strength of concrete structures while effecting savings in materials is to use prestressing. Other fields in which advances can be made are the mixing, transportation to the working point, and placing of concrete, and in work planning. Large-scale use should be made of precast facing shells.

By means of such improvements, it is possible to reduce the cost of massive concrete dams by 10-15%.

In gravity dams, a reduction in size and savings in concrete may be obtained by making wider the construction joints between the dam elements[11]. This reduces the uplift pressure of seepage at the dam base. Good results were obtained with this innovation at the Bratsk, Krasnoyarsk, and Bukhtarma dams.

With the increasing use of wide expansion joints, an advance to the building of buttressed dams is no more than a logical step. In such dams the upstream face is usually inclined, thus increasing the stability of the dam. Compared with gravity dams, buttressed dams permit savings in materials up to 40%. Massive buttressed dams are widely used abroad where they are known as Noetzli Dam. They are built to heights reaching 100 m (cf. Ancipa Dam in Italy with a height of 105 m, Chang Pai Shan Dam—131 m, and Hungan Kiang Dam—145 m, both the latter being in China. Buttressed dams should be given more consideration in Soviet power construction, even in regions of severe climate[12].

The design of Krasnoyarsk HEP provides for the construction of a 120 m high massive buttressed dam, with the powerhouse located between the buttresses. The water is fed to the turbine units through conduits installed at the downstream face of the dam (Figure 53). This design permitted the volume of concrete to be reduced by 1.2 million m^3, compared with a gravity dam for the same duty.

The initial version of Krasnoyarsk Dam specified a 20% slope for the upstream face, and 70% for the downstream face.

Much research work was necessary prior to the construction of the dam. This involved the study of light-weight reinforced-concrete structures (dams, locks, and spillways) which had given tens of years of trouble-free operation in the USSR. In the course of these studies, many proposals were made for improving the design of buttressed dams, construction methods for use under severe climatic conditions, etc.

Foreign experience with buttressed dams is extremely satisfactory. Hundreds of such dams and locks have been erected abroad in the last 50

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years for heads of 5-15 m and with heights of 30-90 m. None of them show any signs of deterioration. The few buttressed structures erected in the USSR are also proving very satisfactory. Thus, the Kuz'minskaya and Beloomut dams on the Oka River, constructed 40 years ago, are still operating satisfactorily. Pererva Lock on the Moskva River has been operating for more than 15 years, and Rybinsk Dam for over 20 years.

Apart from giving worthwhile savings in concrete, buttressed dams produce lower ground pressures — a fact of great importance — and hence are less subject to settling than gravity dams with a soft foundation.

Arch dams of various types are bound to play an increasing part in hydropower construction in the USSR. Upper Magnitogorsk Dam is of multiarch design. It has a height of 10 m and a length of 945 m. The dam, however, exhibited serious shortcomings due to poor design and workmanship and, after construction of the Lower Magnitogorsk Dam, it was flooded and made inoperative.

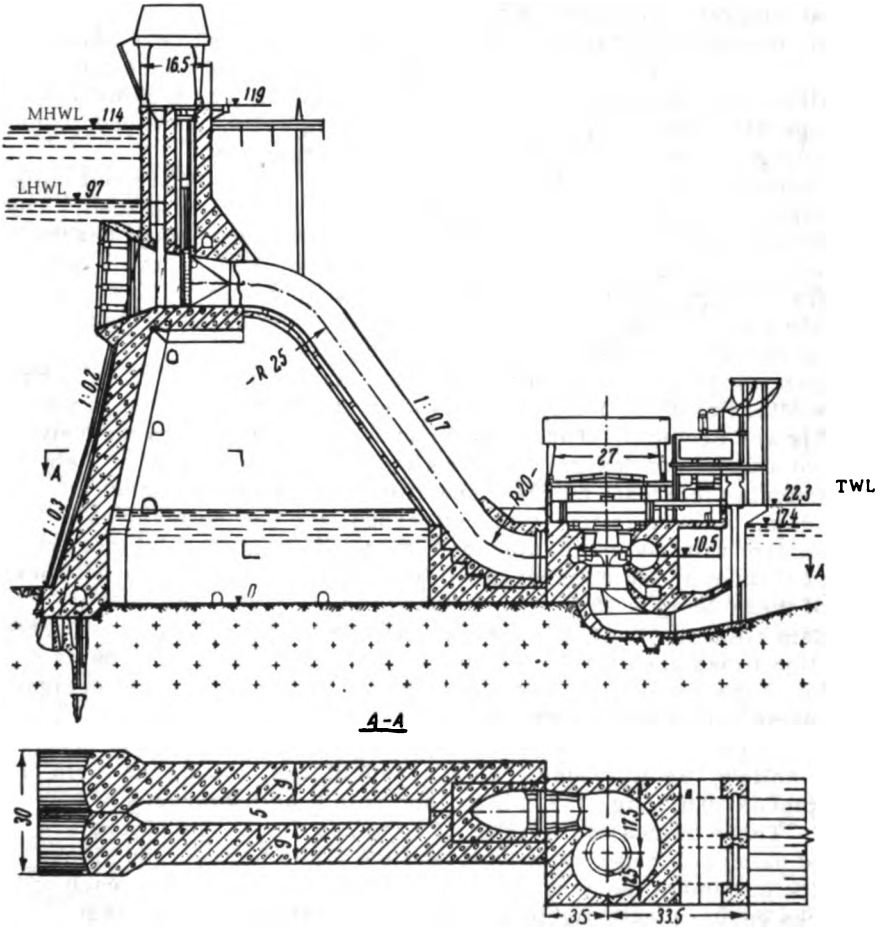

FIGURE 53. Krasnoyarsk HEP. Section through the massive buttressed dam showing the powerhouse (one of the design alternatives).

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The dam of Sinyachikhinskaya HEP on the Neiva River is 17 m high and incorporates a spillway and a buttress section, the latter having a flat deck (the so-called Ambursen type of dam). A novel feature, considering that it is a buttressed dam, is the overflow spillway.

On small rivers with a head not exceeding 20 m, buttressed dams yield savings in concrete of up to 30%, compared with massive gravity dams.

The use of precast reinforced concrete, and combined steel and concrete elements will no doubt lead to further reduction in dam weight and thus in cost.

During the thirties, precast, reinforced-concrete facing shells were used in the construction of the Lower-Svir, Uglich, and Rybinsk power plants, these being the very first instances of this technique. In the construction of Volga HEP im. XXII Congress of the CPSU, more than 250,000 m^2 of such shells 2.5 m × 2.5 m × 8 mm were used. Reinforcing at the rate of 7.2 kg/m^2 was used. Precast concrete was also used for covering roofs and floors. However, precast concrete did not exceed 5-10% of the total concrete used at the site.

In 1950, the position started to improve, thanks to novel developments in design. Precast reinforced concrete is now increasingly used for various structural elements of dams: lining dam faces (earth dams and dikes), superstructures of powerhouses, retaining walls, pressure-tunnel linings, linings for scroll cases for turbines, bridges, etc.

At the construction site of Volgograd HEP, the volume of precast units (226,000 m) did not exceed 4% of the total volume of concrete placed. The position improved with Kremenchug HEP, where this percentage reached 25%. Concrete facing blocks and prestressed reinforced-concrete beams and girders of lengths up to 24 m and weights ranging from 50 to 65 tons were widely used on this site, and also in the building of the Bratsk, Dneprodzerzhinsk, and Mamakan hydropower plants.

Research work carried out at the Gidroproekt Institute im. S. Ya. Zhuk and at the MISI im. V V. Kuibyshev has been of great assistance in the design of power projects. Thus, for the hydro development on the Neiva River, five alternative designs for dams were developed. Two of them are of particular interest: the first specifies a conventional mass-concrete dam, but with lattice-type buttresses; the second features a buttressed dam with a vertical upstream face and monolithic buttresses of precast elements, the buttresses being anchored to the foundation rock. In most of these designs 70% of the concrete is precast. The cost of precast dam elements is 12-20% below that of conventional mass concrete. Construction times are only half those required for conventional dams.

Cellular dams seem to offer great promise, and several novel designs for such dams have already been drawn up.

In a design produced by the Orgenergostroi agency, the dam is made of standard, hollow, lightly-reinforced concrete blocks, having the form of parallelepipeds 10 m long, 1-2 m high, and with a wall thickness of 20-70 cm. These blocks had weights of up to 200 tons. The blocks are assembled using columnar formwork, and the joints between the blocks are filled with cement mortar. A steel diaphragm inserted into each of the front blocks ensures watertightness of the upstream face of the dam.

The dam of the Bratsk project was erected to this design. The figures for the consumption of materials in this dam are excellent; whereas a gravity dam for the same duty would have required 5.7 million m^3 of concrete,

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only 1.3 m^3 of concrete and 3 million m^3 of rip rap were needed. The proportion of precast elements used in the new type is very high: 70-80%.

While in conventional buttressed dams the proportion of precast elements does not exceed 40%, in cellular dams it reaches 80%.

For hydro developments operating with heads of 150-200 m or more, arch dams have definite advantages over other types. Compared with gravity dams, they can be built using a higher proportion of precast units up to 40%.

A major advantage of arch dams is their higher safety factor and stability compared with gravity dams. They are much less prone to cracking, and so far no serious damage to arch dams has been recorded. According to the French engineer, A. Coina, the designer of several dam projects in France and North Africa, an arch dam is more difficult to destroy than to construct[13].

Comparing the profiles of some gravity and arch dams, it is seen that the thickness of arch dams can be as low as 0.14H, even 0.08H, while gravity dams have thicknesses of 0.6-0.9H (H = dam height).

The design and construction of arch dams abroad has reached a very high level indeed. Thus, the Vaiont Arch Dam in Italy has a height of 261.6 m, a crest length of 190 m, and a volume of 360,000 m^3.

The practice of erecting dams in large valleys is increasing. In some countries the ratio of dam length (at crest) to dam height reaches 5-7, and in France even 10-11.

In the past, arch dams were seldom erected in the USSR, as conditions for such dams are less favorable.

In the Soviet Union, an arch gravity dam was erected on the Kara-Koisu River near the village of Gergebil' in the Daghestan (1930-1936). The dam height is 52 m, its base width is 20 m, and its crest width 2 m; the volume of concrete used was 21,000 m^3.

Another notable arch dam, at Ladzhanuri HEP in Georgia, was finished in 1960. The dam has a height of 67 m, a base width of 7.6 m, a crest width of 2.5 m, and a crest length of 127 m; the central arch angle is 125°. Only 25,000 m^3 of concrete were required against 112,000 m^3 for an equivalent gravity dam.

A recent trend in hydropower construction is to regard arch dams with more favor than was previously the case. Thus, according to the Gidroenergoproekt, designs have been drawn up for three arch dams having heights of 50-100 m, nine dams with heights of 100-200 m, and seven dams with a height above 200 m.

It is intended to erect arch dams in regions of the USSR where they have a cost advantage over other dam types. Examples are the 235 m high dam for Inguri HEP in Georgia, and the 225 m high dam for Sayan HEP on the Yenisei. For high-head hydropower stations (300-700 m) with underground powerhouses, e.g., Tatev HEP on the Vorotan River in Armenia, the arch dam, with a volume only a third that of conventional dam types, is the most appropriate type of water-retaining structure.

Earlier in this text details were given of Inguri Dam which, after its completion, will be the highest arch dam in the world[14]. A major advantage of the arch dam is its reduced construction time compared with rock-fill dams.

In Russia, local materials, earth and stone, have been used in dam building for a very long time. Thus, the 18 m high Zmeinogorsk earth dam constructed in the eighteenth century is today still in perfect condition.

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Another example of good workmanship is the earthfill (sand) dam constructed in 1807 at the Sestroretsk Arsenal near St. Petersburg. After 50 years of operation this dam was still in perfect condition.

From archive records it is known that this dam was made of fine sand without reinforcing by steel-piling, i.e., the dam body was made entirely of earthfill (Figure 54). Its length was 170 m, crest width 32 m, and height 5.3 m. The embankments of the dam have a height of 1.5 m at their base. Seepage is always present in the dam but this causes no danger and for the last 20 years no repairs have been needed[15].

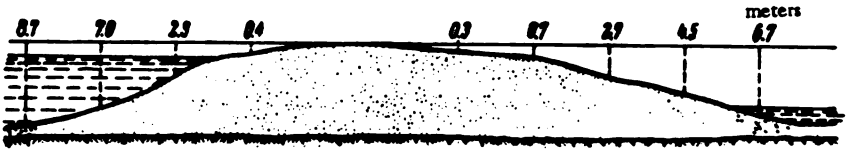

FIGURE 54. The sand dam built in 1807 at Sestroretsk Arsenal; after an early nineteenth century drawing.

In the years following the October Revolution, dams were constructed mostly of homogeneous soil (e.g., the dams at the Bobrikovskii industrial complex, and Bozsu Dam). Later, earth dams were made impervious by incorporating diaphragms and cores of plastic materials (sandy loam, clay, etc.).

The highest earth dam in the USSR (87 m) is far from a world record[16]. It must be remembered, however, that the Soviet dams of this type were erected under extremely difficult conditions.

Terek Dam in the Northern Caucasus is built on peat, previously considered to be completely unsuitable for dams. Many earth dams and dikes of the Volga-Moskva Canal were built on similar soil. Peat has even been used for impervious diaphragms and for aprons [sic]. In 1932 a special sand-peat layer-type diaphragm was developed and laboratory tested. It was for use on the White Sea-Baltic Sea Canal. A similar diaphragm, consisting of three peat layers and two sand layers, has been used in Akulovskaya Dam.

The old type of earthfill dam with a clayey core (exemplified by Pestovskaya and Pyalovskaya dams) is no longer in use, being superseded by dams with a plastic-material diaphragm. This adjoins the apron which is on pervious ground (e.g., Khimki and Akulovskaya dams).

Rigid diaphragms, which are particularly advantageous for dams on rock foundations, have also been used successfully in dams on soft soil (e.g., Ivankovo Dam). One of the dikes along the White-Sea-Baltic Sea Canal has a diaphragm of wood logs (Shavanskaya Dam).

Experimental and practical studies have permitted Soviet engineers to erect large dams with minimum requirements of materials and labor under the most adverse geological conditions. A brilliant example is the dam of Svir HEP, which was erected on morainic soil (heterogeneous clayey deposits containing sand interlayers and boulders).

It was not easy to erect the first Soviet earth dam (the 41 m high Irkutsk Dam) under the severe climatic conditions of Siberia. The dam, which has a volume of 9 million m^3, was filled by dredges and compacted by means

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of the trucks that transported the earth to the site. The dam was filled with locally available gravel, the core being of clay. Filling was carried out round the clock, even when the air temperature dropped to -40° C.

Of particular interest is the first Soviet dam in a permafrost region. The dam is being constructed on the Irelyakh River; it is required to create a storage lake for water supply to the town of Mirny. The dam will have a height of 20 m and a head of 12 m. It is being constructed during the summer months using thawed soil as filling. With the approach of winter, the dam core freezes. It is kept at below-zero temperatures by blowing cold air into the core, through holes drilled in the dam body.

There has been an increasing trend to dispense with steeply sloping dam shells, since these require costly concrete lining and special inverted drainage filters. The embankments are given a gentle slope (1:10 to 1:20). This departure from conventional dam design (e.g., Volga HEP im. XXII Congress of the CPSU), has proved very economical. In the above-mentioned dam they reached 15 million rubles, and in Kremenchug Dam as much as 25 million rubles.

However, under the conditions prevailing in Soviet power construction, it is [normally] cheaper to construct rock-fill dams. Before the October Revolution, there were almost no dams of this type. Several rock-fill dams have recently been constructed, among them the Matkozhnenskaya, Tishinskaya (Ul'ba) dams, and a few larger dams, Khrami, Gyumuch, and Shirokovskaya dams. The semi-rock-fill dam on the Kos'va River is made of rock-fill and masonry. It has a height of 40 m. The upstream face is of masonry, and there is a wooden diaphragm. Gymuch Dam, which is 30.5 m high and 105 m long, has a steel diaphragm. The largest rock-fill dam in the USSR, Khrami Dam, also has a steel diaphragm. Investigations by Puzyrevskii and (earlier) by Dobrotvorskii proved the feasibility of combined water discharge both over the spillway crest and through the diaphragm body (by seepage)[17].

Figure 55,a shows a rock-fill spillway dam with a concrete diaphragm in accordance with a proposal by Puzyrevskii. The dam, which is intended for a head of 25 m, consists of a sandy core with a clay diaphragm between the rock-fill spillway sections. The water is discharged both over the spillway and by seepage through the rock-fill core.

Tishinsk Dam (Figure 55,b), designed by Puzyrevskii and constructed in 1934, has a series of novel features. The dam, which is 10 m high and 110 m long (crest length), consists of a sandy-loam core covered with stone masonry facing. A central masonry diaphragm, protected by a wooden facing, is covered by a concrete slab. For the downstream face, rip rap filling and cribwork facing were used. The dam has been in operation without any serious trouble for many years, discharging water at up to 4 m^3/sec per meter of crest length, and even ice blocks up to 1 m in size.

Another interesting suggestion by Puzyrevskii is the construction of a highway across the crest of a rock-fill dike.

An interesting dam has been erected on the Vilyui River in the permafrost region. Vilyui Dam is 67 m high, 562 m long, and has a volume of 2.3 million m^3. The filling is run-of-quarry stone. The upstream side has a facing of pebble-gravel material with a two-layer drainage filter.

There is an increasing tendency with large dams to use steeper slopes for dam embankments (1:3 to 1:4), and to reduce the size of some of the more costly elements needed to ensure watertightness and prevent seepage

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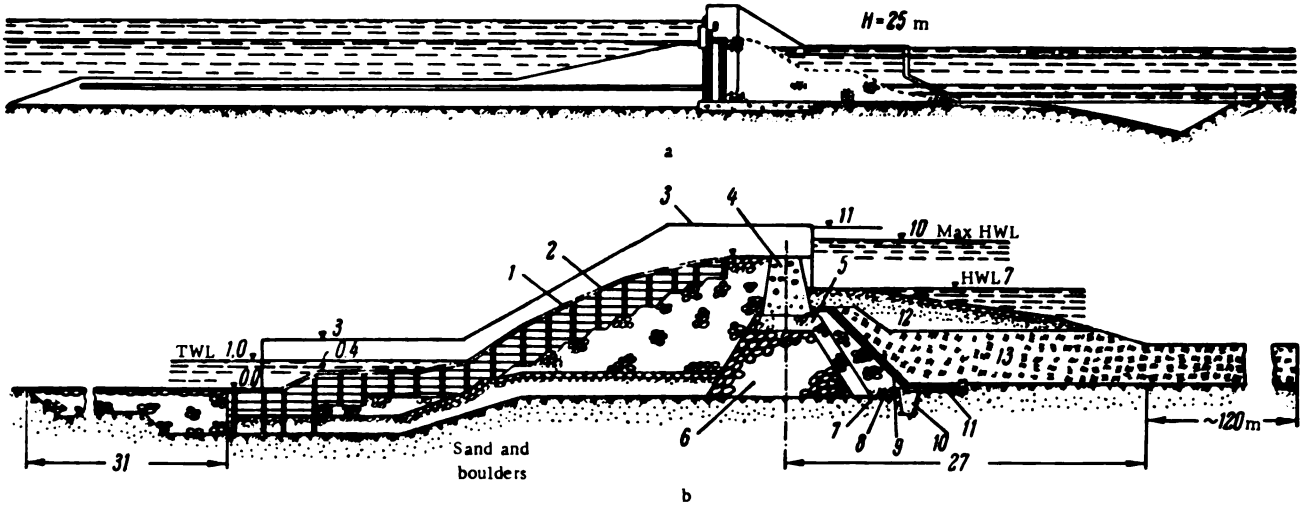

FIGURE 55. Spillway dams built of locally available materials (designs by N.P. Puzyrevskii)

a — design of dam for the Volga (25 m head); b — Tishino Dam on the Ul'ba River (Altai Region).
1 — cribwork; 2 — wood floor; 3 — crest; 4 — boulder-concrete filling; 5 — soft filling; 6 — masonry; 7 — mass concrete; 8 — inverted filter; 9 — asphaltic concrete; 10 — cutoff; 11 — concrete slabs; 12 — sand; 13 — sandy-loam apron.

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damage (facings, diaphragms, etc.). These elements are frequently prefabricated[18].

The construction of dams from local materials may be carried out with conventional (dry-filling) or hydraulic-filling methods.

Nurek HEP in Tadzhikistan will have a very high dam (291 m) made of rockfill, with a sandy-loam core protected by a sand-gravel facing (Figure 56). Other alternatives are still being studied, all of which will undergo careful analysis. Nurek Dam[19] will be one of the largest in the world.

New designs of earthfill spillway dams that can replace concrete spillway dams have been developed.

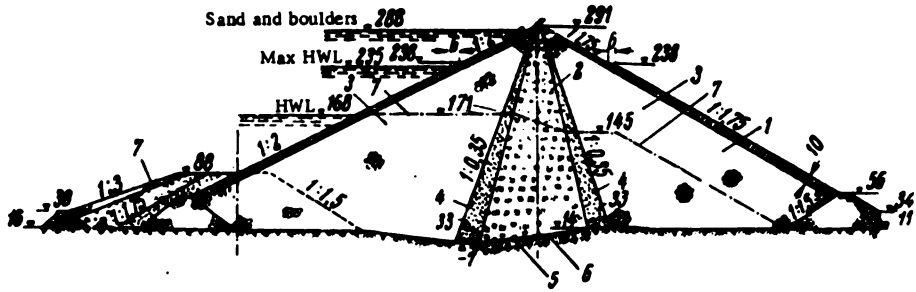

FIGURE 56. Nurek rock-fill dam

1 — constructional cofferdam; 2 — sandy-loam core; 3 — rip-rap; 4 — two-layer pebble filter; 5 — core base with a cement grout curtain to a depth of 8 m; 6 — layer of concrete, 10 cm thick; 7 — upper limit of earthfilling in the first stage of construction.

Rybinsk Dam (height 33 m, length 470 m), which has a filling of sandy soil, is one of the largest dams of this type. The upper section of the upstream face is protected against the action of waves by concrete slabs. The lower section of the face, which has a slope of 1:10, has no special protective lining. Although the filling of the dam was carried out under difficult climatic conditions, the dam successfully withstands the high loading due to water pressure.

The height of earthfill dams constructed in recent years in the USSR is steadily increasing, hydraulic filling being the principal construction method. To mention but a few: Kama, Gorki, Kakhovka, Mingechaur, etc. At some of these dams, the daily rate of hydraulic filling was impressive, e.g., 300,000 m^3 at Volga HEP im. Lenin.

Among dam builders, the opinion is still widespread that the most effective way of increasing the rate of filling and guaranteing the safety of the building operations is to give dams a wide core and a flattened profile. A serious drawback of such a profile is the large amount of earthfilling necessary. Abroad, dams with such a profile (e.g., Fort Peck Dam in the U.S.A.) have frequently suffered serious damage. Special methods are therefore required to check the stability of such dams.

Soviet dam builders are gradually abandoning the use of a normal core of fine-grain soil in earthfill dams, using instead a coreless construction or a very thin core. Such dams were erected at the Upper Volga plants.

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In dams with a thin core, the latter is made of sandy material and its width is reduced to 1/5 of the total dam width.

Soviet practice in earthfill-dam construction differs from American practice . In the USSR, hydraulic filling is continued up to the dam crest, while in the U.S.A., the upper 4-9 m of the dam are usually compacted. In the USSR, the upstream face of earth dams are generally lined with concrete which, in addition to imparting stability, provides seepage protection. Experience in the use of such dams (1933-1944) showed their high reliability.

The Tsimlyanskaya Dam, the largest earthfilled structure in the USSR[20] (26 million m^3),was filled with fine sand mixed with loam. The dam has a fine sand core, the width of which does not exceed 1/5 of the dam width. The profile of this dam was built up from top to bottom by hydraulic filling; the section of the dam above maximum headwater level has no core at all. The upstream face of the dam is protected by concrete slabs. During construction the daily increase in the height of the dam was 2 m. To reduce seepage flow, special well-point filters were installed at a depth of about 10 m at the downstream face.

Mingechaur Dam on the Kura River (Figure 57) is the highest earthfill structure in the USSR; the dam, which was constructed in 1953, has a height of 87 m.

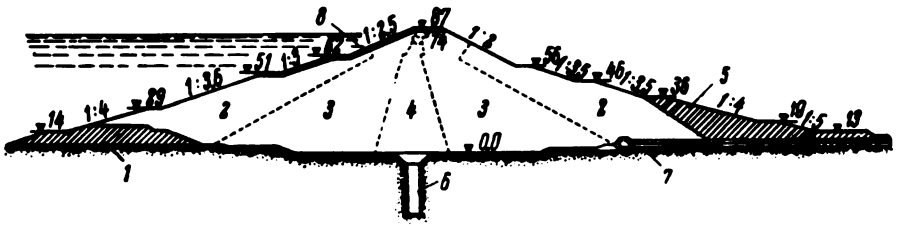

FIGURE 57. Mingechaur earthfill dam

1 — earthfill dam toe; 2 — outer shells of dam; 3 — intermediate shell; 4 — core; 5 — river-gravel filling; 6 — cement-grout curtain; 7 — drainage outlets; 8 — concrete lining.

The volume of the filling in Mingechaur Dam is 15 million m^3. The lack of experience in the construction of such dams[21], particularly in earthquake areas, necessitated much research and experimental work. The dam builders successfully coped with their task, thus disproving foreign criticism.

Another remarkable earthfill dam made of fine sand is Kakhovka Dam on the Dnieper (height 30 m, length 1300 m). The site on which the dam was built was thoroughly investigated beforehand by sinking a shaft down to a depth of 30 m. These investigations showed that the shear modulus of the rocks was 0.5, not 0.4 as adopted in the design. The time required on site for building dams is being reduced: Mingechaur Dam was completed in a record time of seven months. It was two years in the design stage.

The dam of Volga HEP im. Lenin is a hydraulically filled earth dam made of local sand. The dam has a height of 45 m, a length of 2800 m. The volume of fill is 30 million m^3.

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Hydraulically filled dams are very cheap to produce and should find increasing use. However, filling methods must still be improved, the working rate increased, designs improved to allow a reduction in core width (dam profile) and crest width, etc.

Abroad, particularly in the U.S.A., hydraulically filled dams are gradually being displaced by dry-filled earth dams[22]. This is apparently due to the following:

1) a higher degree of mechanization of dry filling;

2) extensive utilization of soil excavated from pits, canals, tunnels, chutes, etc., and the use of narrow core widths;

3) absence of local materials that lend themselves to hydraulic filling.

Economic considerations (the price of fuel for machines, etc.) are also relevant.

Wood dams

The former practice of using wood in dams and various other hydrotechnical structures — buttresses, abutments, bridges, etc. — has not been overlooked.

Timber spillway dams in the USSR have novel design features, many of which are unknown abroad. An example is the crib-type Shavanskaya Dam on the White Sea-Baltic Sea Canal (height 12 m), which has rip rap facing and concrete abutments. Buttressed timber dams were also used on this canal system (e.g., the 8 m high Vygostrovskaya Dam). Many other structures on this canal were made of wood.

Powerhouses

A review of spillway dams would not be complete without a discussion of the new trend to combine the spillway dam and the powerhouse into a single structure. This allows a considerable reduction in the length of the concrete structures of the dam, and thus in cost. An example of this construction is found in Volga HEP im. Lenin, where a 35% reduction in the length of the structures was achieved, and in Uch'-Kurgan HEP where the dam length was reduced by 67 %. In Irkutsh HEP (Figure 39), Kairakum HEP, Perm HEP, Pavlovka HEP (Figure 58), and Iriklinski HEP there is no spillway section at all, and water is discharged both through the draft tube of the turbines and through the sluiceways. The powerhouse of Volga HEP im. XXII Congress of the CPSU is also of built-in type (Figure 25). This powerhouse accommodates 11 turbine units in two bays, with the sluiceways arranged above the draft tubes. The sluiceways are capable of discharging up to 50 % of the rated runoff. This construction method allowed the length of thedam structures to be reduced by a third. This saved 1,150,000 m^3 of concrete and 55,000 tons of steel reinforcing and steel structures.

For technical reasons it was decided to reduce the number of bays in the Kremenchug Spillway Dam from 15 to 10 which permitted the powerhouse to be increased [in height] without any additional excavation and allowed the accommodation of another four turbine units.

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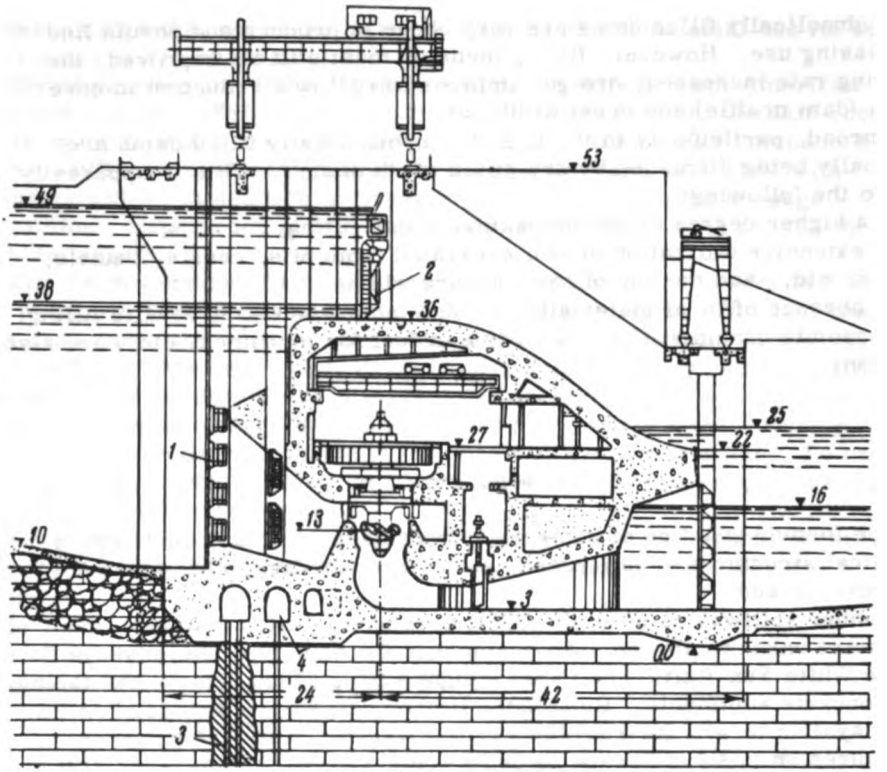

FIGURE 58. Pavlovka HEP on the Ufa River showing built-in powerhouse (The plant was erected in an area with a very pronounced karstic character)

1 — trash-retaining structures; 2 — main gate; 3 — cement-grout curtain; 4 — drainage and water supply galleries.

In Ortachaly HEP on the Kura River, the turbine units were installed in the dam piers—the first time this practice has been followd in the USSR. The pier was made 13 m wide to accommodate the horizontal turbines, while the spillway dam had 14 m wide bays covered with plain sliding gates. Compared with conventional designs this construction yielded savings of 25% in cement and concrete, 2% in steel structures, 30% in reinforcing steel, and 7% in capital investment. The length of the concrete structures was 20% less than it would have been in a conventional design.

In line with the new trends to achieve more economical shapes of hydrotechnical structures, new layouts of turbine units are now being used with the thrust bearing installed on the turbine cover. This arrangement reduces the height and weight of the turbogenerator unit by eliminating the lower radial-arm bracket of the generator (Figure 66). Reduced height of turbine units permits a reduction in the height of the powerhouse, and thus in the volume of the construction work (e. g., Tsimlyanskaya and Perm HEPs)

The powerhouse of Kakhovka HEP is of the built-in type (Figure 17) and has sluiceways. This design permitted the length of the spillway section to be reduced by 70 m. For the first time in Soviet practice the draft tubes were of the low type, which permitted the excavation pit to be correspondingly less deep.

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Perm HEP on the Kama River commissioned in 1959 (Figure 59) is an example of the new more economical type of hydrotechnical structures being used to good advantage. The power station has a large number of turbine units, and a built-in powerhouse. At the design stage it was decided to divert the nappe over the top deck of the powerhouse, and this permitted the foundation mat of the powerhouse to be raised by 14 m. It also allowed the concrete structures to be located in the top layer of the basal rocks. Extensive gypsum interlayers occur at a depth of about 25 m below the dam base. To protect these layers against the leaching effect of the seepage flow; the upstream side of the plant is provided with a special apron 100 m long, which adjoins a cement-grout curtain at its upstream end. At a distance of 65 m from this curtain, below the apron, there is a drainage gallery that collects seepage water retained by the curtain. The upstream face also has a drainage system. The combined spillway-powerhouse-type design permitted a big reduction in the length of the spillway section. The ejection effect[23] of the spilling jet during the flood season tended to increase the operating power of the turbines.

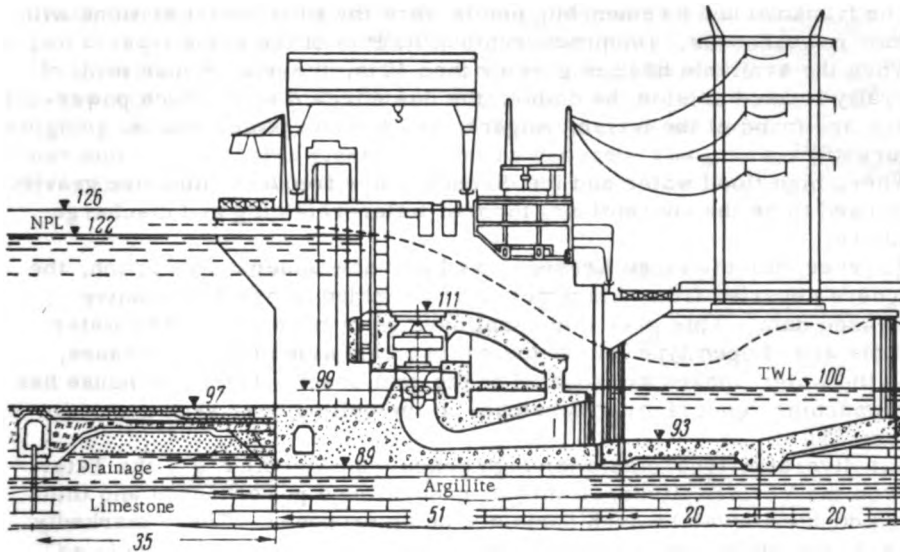

FIGURE 59. Perm HEP, showing the powerhouse built into the spillway section of the dam. The generator bay is accessible through hatches in the floor of the overflow spillway

Locating the thrust bearing in the top cover of the turbine reduced the height by 6 m. This allowed the turbogenerator to be installed within the spillway structure.

The extremely compact design of this station cut down the volume of engineering work necessary. This, in turn, meant that less construction equipment was necessary. This is easily seen from the following figures which are expressed "per installed kilowatt": concrete 2 m^3; earthfill 40 m^3; steel 160 kg.

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Run-of-river plants with built-in powerhouses are now gaining increasing acceptance both in the USSR and in the People's Republic of China (where the Perm type of plant has been adopted for many run-of-river stations).

In applying the principle of built-in powerhouses, more attention must be given to using precast concrete.

Another method of reducing capital costs in hydropower construction which is gaining increasing acceptance is the use of outdoor and semi-outdoor powerhouses. The former make special buildings for power equipment completely unnecessary.

The first semi-outdoor powerhouse in the USSR was built at Ivankovo HEP (Figure 9). The low machine room of the plant houses two Kaplan turbines; it is covered with a light-weight movable floor. The dam and power equipment are served by a portal crane that travels over this floor.

The turbine units are remote controlled.

At Kremenchug HEP part of the power equipment is installed outdoors (Figure 37). The generators are in a low covered hall provided with hatches which allow cranes to have access to equipment. The location of power equipment outdoors simplifies the installation of automatic control and monitoring.

The Ivankovo and Kremenchug plants were the first Soviet stations with outdoor powerhouses. Dneprodzerzhinsk HEP is of the same type.

When the available head is greater than 40 m, the powerhouse is generally located outside the dam on the downstream side. Such powerhouses are found at the Irtysh, Angara, and Yenisei power plants (Figure 40)[24].

Where high flood water and ice discharge are frequent, massive gravity dams used to be the conventional form of water-retaining and discharge structure.

However, for the large Krasnoyarsk Plant now under construction, the designers departed from this practice and decided to erect a massive buttressed dam. This gave important savings in materials. The water conduits are of open type laid at the downstream side of the buttresses, while the water intakes are located at the dam crest. The powerhouse has a low machine room (4 m) with hatches in the ceiling over each generator (Figure 53).

For diversion-type plants for high heads (300-700 m) e.g., the Tatev plant on the Vorotan River, Armenia, underground powerhouses and thin-walled double-curvature arch dams are being proposed. These markedly decrease the amount of concrete needed.

The existence of a narrow gorge with steep banks means that access to construction sites will be difficult. Conditions such as these favor the use of an underground powerhouse and water-conveying tunnels. It should also be remembered that the maintenance of underground concrete structures, not exposed to the weather, is much cheaper than the maintenance of conventionally located structures. The electromechanical equipment for underground stations is essentially the same, horizontal turbines being used. Some additional ventilation is also required. Niva No. 3 HEP inside the Arctic Circle, has an underground powerhouse (13.5×76×27 m) (see Figure 13 earlier in this text).

Another notable achievement of Soviet power construction is Inguri HEP in Georgia (1400 Mw). This station is equipped with 233 Mw units and has

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an underground powerhouse only slightly smaller than that of the Nechako-Keman hydroelectric power plant in Canada, which is the largest underground powerhouse in the world.

The trend to use precast and preassembled structures as much as possible is steadily increasing.

In the construction of Volga HEP im. XXII Congress of the CPSU, the linings of the draft tubes, turbine scroll cases, and some superstructure parts are entirely of precast concrete.

The powerhouse of Kaunas HEP was made of precast concrete shells, the first time such a technique was used in power construction. Half the concrete used in this plant was precast, only the foundation mat and some of the internal partition walls being of mass concrete. The heavy floors were made without any scaffolding, the weight of the flooring being carried solely by preassembled lightly-reinforced concrete elements.

The entire superstructure of the powerhouse at Gamut HEP was made of precast concrete. This speeded up construction and effected considerable savings on materials.

With the advance in the methods of using precast elements, it is to be hoped that their usage will increase to become 80% of all concrete work.

In the construction of several new power plants (Saratov, Sovetsk, Kiev, etc.), precast-concrete elements, in the form of large hollow blocks weighing up to 75 tons, were used for the submerged sections of the powerhouse and dam. At this plant, 56% of the concrete was precast (station average) (see Table 26).

TABLE 26

Precast concrete used in the construction of Saratov HEP

Type of structure	Volume of concrete, thou. m^3		Percentage of precast elements
	total	precast concrete	
Powerhouse	555	365	65.7
Spillway dam	66	37	56.0

The plant is being built without a machine room [outdoor station] and will be equipped with a gantry crane for the mounting of equipment and for repair work. The submerged structures of the plant are to be made of precast elements, some of the blocks weighing up to 75 tons.

The floor of the Saratov lock is monolithic and the walls are made up of preassembled buttresses with connecting slabs. Here, the volume of precast elements reaches 96.3%. Precast concrete is also being used for the overfall wall, stilling structures at the upper end of the lock, etc. The maximum weight of blocks used for these structures is 100 tons. The volume of constructional concrete per cubic meter of useful volume of the locks is 0.57 m^3, i.e., only a third the amount used in the locks of both the Volga plants and the Volga-Moskva Canal. Comprehensive mechanization and the use of precast elements result in speedy construction (two years).

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In the construction of the Sovetsk Plant on the Neman River the percentage of concrete handled in precast form will be still larger. For the first time Soviet constructors will use flow-line methods of handling concrete, using the construction facilities of the nearby town of Kaunas. The powerhouse will be built into the spillway dam and will accommodate horizontal bulb-type turbine units. The straight draft tubes are to be made of precast channel-beam elements weighing up to 43 tons. The volume of precast concrete will be 75% (cf. 56% in the Saratov Plant).

The design for the Kanev and Kiev plants, which are to be erected on soft soil, involves the use of cellular structures made of precast-concrete slabs. These will be placed on edge and filled with sand.

In subsequent projects up to 80% of the concrete will be precast; the intention is that these elements should gradually replace monolithic concrete.

The design of the fish lift of Volga HEP im. XXII Congress of the CPSU (also known as the Volgograd fish lift) was based on the one built at Tsimlyanskaya HEP (Figure 15). However, the later version differs from its predecessor in size, carrying capacity, and the method employed for the water supply to the inlet flume[25].

The Volgograd fish lift (Figure 60) takes the form of a two-lane fish lock, with upstream and downstream supply flumes located in the left-hand bay of the first section of the spillway dam (Figure 33). The vertical shaft of the fish lock has a depth of 27.5 m, the horizontal section being 8.5×8.5 m. The shaft is provided with gates for filling and emptying. In front of the shaft is a 13 Mw turbine unit. The bifurcated draft tube and the gates at the outlets of the draft tube, which gives access to the bottom section of the shaft, permit the passage of fish into one of the shafts (without the need to shut down the turbine), while the fish are accumulating in the downstream flume of the second shaft. The water leaves the draft tube and enters the downstream flume at a discharge rate of 100 m^3/sec, thus creating a fast flow at the entrance to the flume that sucks the fish into the flume. The velocity of this flow may be regulated. The fish that gather in the downstream flume, near the shaft, and within the shaft itself are directed automatically by means of a screen with electromechanical barrage elements. The movement of fish into the shaft and at the shaft outlet into the upper pool is controlled by a special rotary screen. One complete cycle of the two lock shafts operating in turn takes 54 min. The lowering of the rotary screen takes 3 min and its motion cycle takes 9 min. The discharge of water through the turbine into the downstream flume takes 41 min. Filling the shaft with water to the level of the upper pool of the lock, with the simultaneous raising of the rotary screen, takes 10 min.

Soviet power constructors can be proud of the fact that their work is on a level with that being done in other countries, and that the projects realized in the USSR show evidence of the bold decisions and creative ability of the builders.

Lenin who deeply believed in the creative ability of his people, was convinced that the Soviet regime would take the lead over the capitalists...[26]

Russia's backwardness in power construction has been overcome, and today foreign specialists have only words of praise for Soviet achievement[27].

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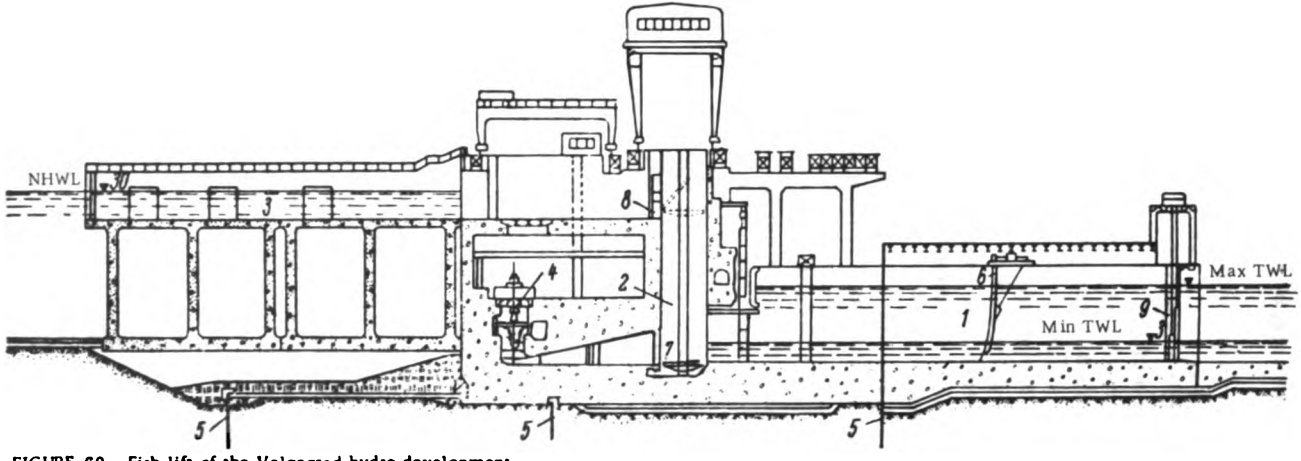

FIGURE 60. Fish lift of the Volgograd hydro development

1 — inlet flume; 2 — fish-lift shaft; 3 — outlet flume; 4 — turbine unit; 5 — steel-sheet piling; 6 — movable screen and screen mechanism in the downstream flume; 7 — horizontal rotary screen; 8 — gate at the upper-pool position; 9 — lower-pool gate (regulation and repairs)

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SCIENTIFIC RESEARCH AIDS TURBINE DESIGN

Great achievements have been obtained in the field of turbine construction. Soviet designed and manufactured hydraulic turbines of very large size are operating in the USSR and the neighboring countries of the people's democracies.

But the road to these successes was not easy. The First World War reduced Russia's industry to ruins.

Not till the twenties did the Soviet power-construction industry recover from the heavy losses it had suffered during the war. In the GOELRO Plan, which played such a crucial part in the general electrification of the country, much space is devoted to the problem of turbine construction[28].

The Pirvits Works (see earlier in this text) was taken over by the Moscow Council of National Economy; young specialists straight from the lecture rooms of the MVTU were sent to this plant, which started to manufacture the first turbines with capacities of 15-75 kw. The plant was actively assisted by the head of the rotating machines department of the MVTU, Professor I.T. Kukolevskii[29]. An outstanding achievement of this plant was the building in 1920 of the first 50 kw turbine for the Yaropoletskaya HEP — a station which was erected on Lenin's initiative.

In 1924, the production of turbines at the Pirvits Works was temporarily transferred to the Krasnaya Presnya Works, Moscow. By the end of the same year, the plant produced the first horizontal Francis turbine. It was a 200 kw 200 rpm machine, designed for a head of 8 m. The turbine which was for Petrozavodsk HEP had an efficiency of 86%.

In 1925, a team of the Krasnaya Presnya specialists, under the guidance of Professor Kukolevskii, constructed and tested at the hydraulics laboratory of the MVTU one of the first propeller turbines, designed using the Joukowski condition[30]

In 1926, the Plant im. Kalinin (formerly Dobrov and Nabgol'ts), which had been temporarily shut down, was reopened. The production of hydraulic turbines, which had been started at the Krasnaya Presnya Plant, was continued in the reopened plant. Between 1926 and 1927 the plant manufactured the first three Kaplan turbines for Syzran' HEP. These were rated at 880 kw with a 13 m head. In 1928 the plant manufactured a 1650 kw Kaplan turbine (head 110 m) for Leninakan HEP in Armenia.

In 1929, the same plant constructed an axial propeller turbine of 280 kw for a head of 4 m. The design of this machine was based on model tests carried out at the MVTU laboratory. The water wheel had a diameter of about 2 m. This turbine was installed at Rublev HEP. In 1930 this plant produced for Kadyrin HEP the first four vertical Kaplan turbines, each rated at 3300 kw. In 1934, the plant produced for Kanakerskaya HEP large (11 Mw) vertical Kaplan turbines, designed to work with a head of 169 m. These turbines were for a long time the largest vertical Kaplan turbines produced in the Soviet Union.

The ever increasing need for hydraulic turbines led to the expansion of turbine construction. However, the plant continued to produce only small-size turbines. More than 300 turbines, representing a total power of about 130,000 kw, were manufactured at the Plant im. Kalinin during the time it was in existence.

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The expansion of turbine construction made necessary the reorganization of the hydraulics laboratories. Accordingly, the Soviet Government organized the All-Union Scientific Research Institute for Hydraulic Machines (VIGM). Cavitation problems were given particular attention and special cavitation-testing units were created at the MVTU Laboratory (in 1932) and at VIGM (in 1934).

Much attention was being given to the development of turbine construction in Leningrad as well as in Moscow. The old shops of Leningrad Metal Works (LMZ) were reconstructed and adapted to the production of hydraulic turbines. At that time, the Soviet Union started to implement the GOELRO Plan.

In 1924 Leningrad Metal Works manufactured the first large hydraulic turbine for Okulovo Paper Mills. The turbine was of the Kaplan type; it had a steel scroll case and a water wheel of 1 m diameter. The turbine was rated at 370 kw, 214 rpm, and 14 m head. The turbine was much more advanced than the largest turbines ever produced in Tsarist Russia (see Table 1). It was developed by the plant design office, under the guidance of I.N. Voznesenskii and for a long time was used as the model for later turbine designs.

The role played by Voznesenskii in the development of Soviet turbine construction must not be overlooked. Until the end of his life he gave his services to the Leningrad Works. He improved the methods of making hydrodynamic turbine calculations and extended the theory of turbine control and regulation. In 1932, the Krasnyi Putilovets (now Kirov) Works designed, under his guidance, the Kaplan turbine for Kochetovskaya HEP. The turbine was built at Leningrad Metal Works, and from that time, foreign designs for Kaplan turbines were not granted patent rights in the USSR.

In 1924 Leningrad Metal Works produced for Akhaltsykhskaya HEP in the Caucasus a horizontal Francis turbine rated at 55 kw, 600 rpm, 7.5 m head. During the first year of turbine work the construction the Leningrad Plant produced two turbines with a total power of 425 kw.

The following year (1925) turbine construction started at many Soviet plants but in every case it was regarded as a secondary line of production. Under such conditions the rapid development of turbine construction was impossible and a decision was made to concentrate the manufacture of hydraulic turbines in plants with the necessary facilities. These plants were Leningrad Metal Works and the Plant im. Kalinin, Moscow. Until the first Five-Year Plan more steam than hydraulic turbines were produced, but the position changed radically during the second Five-Year Plan period.

The letters LMZ (Leningrad Metal Works) are now well known both in the USSR and abroad.

In 1925 LMZ produced 9 turbines of total capacity 4560 kw.

In 1926 the largest Soviet turbines were rated at 1100 kw. Two such turbines were installed at Leninakan HEP; the turbines operated at 750 rpm with a head of 110 m. The machines were used for many years without any important overhaul being necessary.

By 1926 Soviet hydroturbine construction was properly established. Turbine-building plants were equipped with up-to-date machinery, and production increased at an unprecedented rate. The development of large

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turbines suffered from this production increase, because the Soviet national economy required many small turbines for the innumerable low-capacity regional, district, and local power stations.

During the period 1924-1928, LMZ produced turbines with a total power of more than 23,000 kw (see Table 27). This is a third of the total power of all the turbines produced during the 44 years preceding the October Revolution[31]. The average power of Soviet turbine units was 490 kw. During this period Soviet designers developed a number of novel turbine designs. Thus the first turbine with automatic regulation (produced by LMZ) was built in 1927. This development gave high power output with cavitation-free operation[32]. Most turbines produced in Tsarist Russia had manual control, or even no governor at all.

TABLE 27

Construction of hydraulic turbines in the USSR, 1924-1928

Year	No. of turbines built	Total power of turbines produced	Unit power of turbines, kw	
			mean	maximum
1924	2	425	211	370 (for Okulovskaya HEP)
1925	9	4,560	496	3,600 (for ZAGES HEP)
1926	8	3,475	388	1,100 (for Leninankan HEP)
1927	16	4,820	301	—
1928	12	9,950	829	—
Total for 5 years	47	23,150	493	

The production of hydraulic equipment in the USSR made it possible gradually to dispense with the import of foreign equipment.

During the Five-Year Plans, Soviet hydraulic-turbine construction steadily progressed, raising the unit power of turbines, increasing production, and improving design. In May, 1928, the hydraulic-turbine laboratory of Leningrad Metal Works was opened. In the same year, the plant produced turbines with a total power of 5552 kw. (The total power of turbines produced by all Soviet plants during this year was 9950 kw). The following year, LMZ manufactured for Rion HEP two Francis turbines, each developing 12.8 Mw with a head of 60 m.

This achievement is seen to be remarkable if it is remembered that the construction of such large turbines was undertaken only six years after this type of machine building had been started in the USSR. It should not be forgotten that most power equipment had still to be imported: the first Soviet hydropower plant, Volkhov HEP, was equipped with Swedish turbines, while the second station, Zemo-Avchaly, had only one Soviet turbine rated at 3600 kw.

By 1929, the average unit power of turbines produced by LMZ had reached 1856 kw — ten times the power of the first turbine built in 1924.

The year 1930 was a period of steady improvement and expansion in turbine production. LMZ passed to the manufacture of large turbines, built using the latest techniques and equipped with automatic governors, auxiliary machinery, etc. For Dzoraget HEP, LMZ built an 8000 kw

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turbine for a head of 105 m. In the same year a horizontal 500 rpm Pelton turbine for a head of 289 m for Gizel'don HEP, and a 294 kw Kaplan turbine for a head of 4.25 m for Pervomaisk HEP were built at the plant. The design of this latter turbine was a mere copy of foreign designs.

In 1931, LMZ produced turbines with a total power of 52,500 kw; among them was the fourth 12,800 kw turbine for Rion HEP, two more 8100 kw Pelton turbines for Gizel'don HEP, and a Francis turbine rated at 8000 kw for Dzoraget HEP.

In the period 1930-1932, LMZ designed and built 14,500 kw Francis turbines (head 35 m) for Skhodnenskaya HEP and 15,300 kw turbines for Niva No. 2 HEP (head 36 m). These turbines had an efficiency of 92.2 %, which was better than the efficiency of comparable foreign equipment. For the Zemo-Avchaly HEP, LMZ built a 12,500 kw Kaplan turbine for a head of 23.5 m; the runner diameter was 3.6 m. This turbine was equipped with a novel crankshaft drive for the blade-adjustment system[33]. The turbine for ZAGES was, at the time of its construction, one of the largest high-head Kaplan turbines[34].

Similar turbines were also built for Tuloma HEP.

LMZ was now geared to supply Kaplan turbines for the many power stations being built. It supplied a 27,600 kw turbine for a head of 11 m for Lower-Svir HEP; the runner diameter was 7.4 m. Although initially all of the four turbines for this station were ordered from the Swedish plant Werkstaden-Cristineham, the fourth turbine was supplied by LMZ[35].

Scientific research work on problems of turbine construction continued both at plants and institutes, and numerous, novel, high-speed Kaplan and Francis turbines were developed and built.

Of course, in eight years the Soviet turbine-construction industry could not reach the level attained abroad after 60 years work, but the gap was being continuously narrowed.

The directives of the XVI Party Congress regarding turbine construction meant building turbines of maximum unit power and producing a steady improvement in design.

The speedy implementation of these directives points to the high rate of construction — only possible under the conditions existing in a socialist regime.

The state of foreign [capitalist] turbine construction was entirely different. As seen from Figure 61, as a result of the economic crisis, the production of hydraulic turbines steadily decreased, even at such first-class plants as the Swedish company Werkstaden, and Newport News in the U.S.A. Apart from the Soviet order for Svir' HEP (see Figure 61, cross-hatched area) in 1929 the Werkstaden Company booked turbine orders totalling only 10,700 kw of turbines, much less than in previous years. In 1930 the production at this company dropped even more, to 9600 kw.

At Newport News the production figures also continued to drop. However, in 1929-1930, thanks to "fat" orders from the USSR for Dnieper HEP, production temporarily rose. In 1929 the company produced four 68 Mw turbines for Dnieper HEP. The total production figure for 1929 was 387,000 kw, and the 1930 figure was even lower.

Before the import of foreign turbines could be discontinued, turbine-production facilities had to be expanded, and the production of metals had to be improved. In line with these requirements, LMZ started the

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construction of a large turbine-building shop in 1931 which was partly commissioned in 1935 and completed in 1937. By this time, LMZ was able to produce large Kaplan and Francis turbines having unit powers in the range 5,000-20,000 kw, equipped with up-to-date auxiliary machinery.

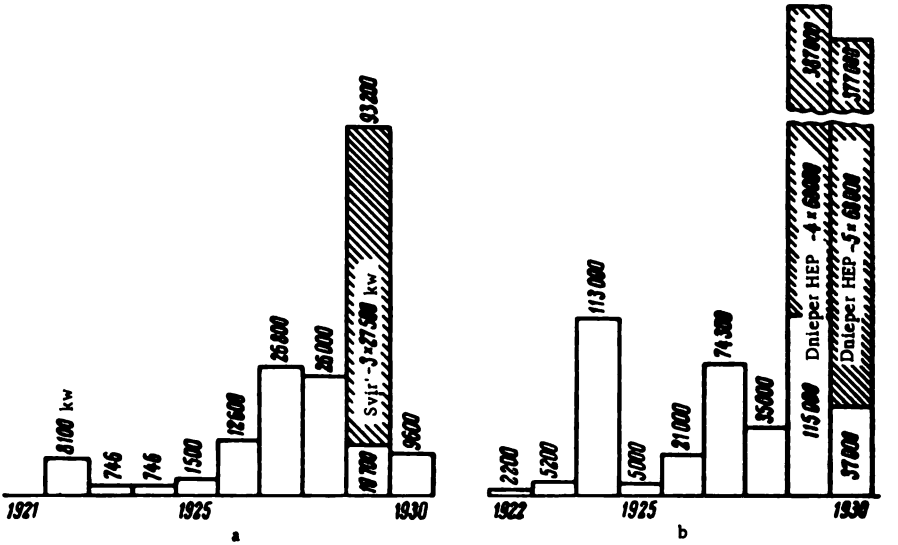

FIGURE 61. Foreign production of hydraulic turbines (1921-1930)

a — Werkstaden-Cristineham, Sweden; b — Newport News, U.S.A.

The ever increasing rate of turbine construction gave no time for guesswork in the design of turbines. The plant developed its own methods of design, calculation, and model-testing techniques. These advances were possible thanks to the invaluable help given by Voznesenskii.

In 1937, the plant produced Kaplan turbines for several of the power plants of the Volga-Moskva canal system: Ivankovo, Karamyshevo, Perervinskaya, Listvyanskaya, Lower-Tuloma, etc. The largest of these turbines — 15,000 kw, runner diameter 5 m, head 13 m, 100 rpm — was for Ivankovo HEP. The turbines manufactured by LMZ had high efficiency, e.g., that of the turbine for Ivankovo HEP (93.7%) was the highest achieved at the time.

The turbines for the stations along the Volga Canal were fully automatic: starting and stopping was controlled from the control desk of the station[38] (Figure 62).

The Francis turbines for high-head operation, constructed by LMZ in 1937 and 1938, were of extremely complicated design. Their power was 25,000 kw with a head of 170 m. The turbines were equipped with disk (butterfly) gate valves of inlet diameter 2.1 m. This type of valve gave better service than other types used abroad.

By 1937, LMZ had acquired sufficient experience to allow a start to be made on the unique Kaplan turbines for the Rybinsk and Uglich power plants.

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These turbines had a power of 65,000 kw with a head of 15.5 m; the water discharge through the runner was 500 m^3/sec, and speed 62.5 rpm. With a head of 20 m the turbine developed a power of 70,000 kw. In 1939, LMZ produced the first turbine for Uglich HEP. The runner had a diameter over the blades of 9 m and the hub diameter was 3.7 m. The height of the runner was 7.5 m; it weighed 304 tons. The runner hub was a massive cast-steel unit weighing about 70 tons and containing the blade-adjusting mechanism for the four blades. The total weight of the turbine was 1300 tons[37]. The turbine chamber (stator) had a diameter of 14 m (as measured at the distributor ring). The main turbine shaft had a diameter of 1.3 m and a weight of 48 tons. The designers had to overcome serious technical difficulties: casting shaped components weighing up to 60 tons, difficult machining, heat treatment, etc. The problem of static balancing of the runner was solved brilliantly. In the years immediately before the war, and just after the war (1944-1945) LMZ built several such turbines.

FIGURE 62. Dispatching control center of the Volga-Moskva canal system.

The design of the generator underwent considerable changes. The umbrella-type generator used with many hydraulic turbines had an electromagnetic device for unloading the thrust bearing during turbine start-up. (The load often reached 2100 tons, far exceeding the load found in foreign machines, e.g., the load on the generator thrust bearing at Bonneville Power Station (U.S.A.) reaches 1350).

Until the construction of the turbines for Volga HEP im. Lenin, the Kaplan turbines of the Uglich and Rybinsk developments were for a long time the largest in the world. For the design and construction of these turbines, which had 9 m diameter runners, LMZ was awarded the Lenin State Prize in 1946.

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The Soviet turbine-building industry showed up well in the supply of turbines for Dnieper HEP, which was completely rebuilt after its destruction by the Germans in 1941.

Earlier it was noted that in 1932 the level of Soviet turbine construction was still below that of foreign manufacturers, and the [original] turbines for this station were purchased in the U.S.A. By the end of the war Soviet plants were able to build large efficient turbines. The plans for the reconstruction of Dnieper HEP provided for the installation of larger turbines, without increasing the dimensions of the submerged part of the plant[38]. It was decided to install six Soviet turbines and three turbines from the American company, Newport News.

The Francis turbines built by LMZ in 1946[39] have a rated power of 75,000 kw (against 62,000 kw of the American turbines). This rating corresponds to a head of 36.3 m and a speed of 83.25 rpm (the maximum available head at the plant is 39.4 m). For this turbine, LMZ designed a new type of runner with a weight of 92 tons, diameter 5.45 m, and length 3.1 m. The runner which was of unprecendented size was an all-cast structure made at the New Machine-Building Plant in Kramatorsk. The all-cast design saved 12 tons of steel per turbine, and reduced the time required for manufacture of the turbine. In American turbines runners of comparable size are made of three sections, joined by special shroud rings. By using an all-cast runner, the weight of the LMZ turbines was reduced by 16% (their weight-power coefficient was 5.8 kg/kw against 7.25 kg/kw for the American turbines installed in the first Dnieper plant[40]). The efficiency was 93% (against 90.3% for the American turbines).

LMZ used welded spiral casings with an inlet diameter of 8 m and a cross-sectional area of 400 m^2. This was the first time such a construction method had been used anywhere. The American turbines had riveted spiral casings. The guide bearing of the turbine was designed for water lubrication and was of simpler design than the American one. The turbine thrust bearing was equipped with a special unloading device that reduced the axial thrust in the turbine. A novel feature of the LMZ turbine was the hydraulic interlock system, which guaranteed the correct sequence of connections and disconnections of the turbine-control mechanisms. The turbine also received a new type UK (all-purpose) governor, notable for its high sensitivity and accuracy of regulation.

Comparative tests of the LMZ and American turbines installed at Dnieper HEP showed the Soviet turbines to have higher power and efficiency. Their maximum power was found to be 80,000 kw (a figure greater than the rated power) and their efficiency exceeded 93%. The Soviet turbines gave 1500 kw more power and were 1% more efficient than the American machines. These latter were less reliable and showed a less sensitive response to regulation than their Soviet counterparts.

The LMZ governor was tested at various hydroelectric plants and exhibited high qualities. Its speed of response was much higher than that of the govenors installed on the American turbines (the Woodworth governor)[41].

Figure 63 shows the characteristics of the Soviet and American turbines, tested with a head of 37.5 m.

The Soviet medium-head Francis turbines are among the best in the world (see Figure 74). In 1949 LMZ was awarded the State prize for oustanding turbine designs.

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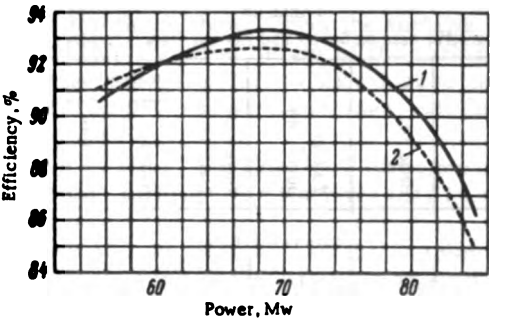

FIGURE 63. Efficiency of the Soviet and American turbines installed at Dnieper HEP (tests conducted with a head of 37.5 m)

1 — LMZ turbines; 2 — Newport News turbines

In the period following the war, Soviet turbine construction completely satisfied the needs of Soviet power construction.

LMZ continued to build 60 and 85 Mw Francis turbines for medium heads, and 55 Mw units for high heads (see Table 28).

In designing 55 Mw Francis turbines for a head of 285 m[42] for Gyumush HEP (one of the plants in the Sevan-Razdan cascade scheme) LMZ had to overcome quite serious technical difficulties: the casting of a 12 ton stainless steel runner with a diameter of 2.65 m, and the design and manufacture of a ball gate valve.

The LMZ turbines for Gymush HEP were installed alongside the Swedish turbines manufactured in 1952. The LMZ turbines are more compact, and are vibration-free. They were commissioned in 1952, without preliminary running-in.

Until recently, more importance was given to the harnessing of the rivers in the European Territory of the USSR, which are mostly lowland rivers with low head. These circumstances obviously determined the design characteristics of the turbines installed at the power stations. These were of low-head Kaplan type for high water discharge equipped, therefore, with large runners (e.g., the turbines of the Volga cascade).

A novel trend was the location of the thrust bearing of Kaplan turbines on the cover plate of the turbine. This permitted the shaft length to be reduced, and allowed their use at spillway power stations located on lowland rivers. Such a design was used for the first time at Perm HEP.

Manufacture of these turbines was started in 1954 at the Syzran Machine-Building Plant. They were installed the same year at Perm HEP. The turbine developed a power of 21,800 kw with a head of 21 m. The runner diameter was 5 m (see Figure 59).

The relatively small dimensions of the spillway powerhouse of this plant meant that the height of the turbine unit had to be kept to a minimum. This was achieved by making the turbine shaft integral with the generator shaft and the runner cover. The height of the turbine was thus kept down to 13.27 m.

This type of turbine was successfully used at Tsimlyanskaya HEP. The turbine was rated at 41,500 kw with a head of 17.5 m (maximum 26 m); The six-blade runner had a diameter of 6.6 m.

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TABLE 28

Comparative data on Soviet and foreign Francis turbines

Year of production	HEP	Head, m	Turbine power, Mw	Runner diameter, m	Weight, tons		Remarks
					runner	complete turbine	
			Soviet HEPs				Efficiency
1925	ZAGES	20	3.6	1.95	—	—	92%
1930	Rion	60	12.6	1.75	6.24	200	91.5%
1932	Dzoraget	105	8.0	1.2	1.54	36	89.5%
1932	Niva No. 2	36	15.3	2.5	11.4	126.5	92.2%
1932	Dnieper (U.S. turbines)	35.5	62.0	6.06	107.0	500.0	90.3%
1939	Komsomol'sk	35.5	21.0	3.0	22.5	229.0	92%
1946	Dnieper (LMZ turbines)	36.3	75.0 (max 81.5)	5.45	92.0	660	93.2%
1946	Dnieper (U.S. turbines	36.3	73.5 (max 79.0)	5.42	—	645	92.5%
1952	Mingechaur	60.0	62.0	4.1	46.43	314.14	92%
1951	—	39.8	85.0	5.45	112.75	631.95	
1952	Gyumush	285.0	57.0	2.65	12.0	165.0	91%
1958	Bukhtarma	61.0	77.0	4.1	52.4	323.5	91.5%
1960	Bratsk	96.0	230.0	5.50	130.0 (with shaft)	800.0	93.5%
1961 (Model)	Krasnoyarsk	95.0	508.0	7.50	250.0	—	94%
1961	Khrami No. 2	324.0	—	—	—	—	Maximum head for which LMZ Francis turbines were ever built
Country			Foreign HEPs				
Japan	Yakuwa	303	35.0	—	—	—	—
Austria	Limberg	436	60.0	—	—	—	Efficiency 93%
Italy	Demonte	383	30.0	—	—	—	—
Switzer-land	Ferrara	520	75.0	—	—	—	—
"	Safienplatz	422	43.5	—	—	—	—
"	Fionnay-Mauvoisin	455	46.2	—	—	—	—
Norway	Vinstra	445	52.0	—	—	—	Efficiency 92%
"	Hemsil	543	37.3	—	—	—	Maximum head for Francis turbines
Mexico	Infernillo	101	173.0	4.8	60.0	—	—
U.S.A.	Grand Coulee	91.5	121.0	5.0	59.0	—	—
Sweden	Harspranget	107.6	117.0	4.1	35.0	—	—
France	Bort-les-Orgues	102.5	117.0	—	40.0	—	—
Canada	Bersimis	266	138.0	3.65	21.3	—	—
Sweden	Stornofors	75	147.2	5.15	55	—	—
Brazil	Furnace	98.7	168.2	6.5	—	—	Largest foreign turbine
Canada	Chute de Passe	195	195.0	—	—	—	

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The location of the thrust bearing on the turbine cover plate reduced the weight of the generator, the total height of the turbine, and hence the height of the powerhouse (see Figure 66). This reduced costs considerably.

LMZ also produced several such turbines, which were installed in 1952 and are still in operation.

At the beginning of 1954, the Khar'kov turbogenerator plant produced the first two large Kaplan turbines for Kakhovka HEP. These were installed the same year (Figure 17).

On the eve of the 40th anniversary of the October Revolution, the world's largest hydroelectric plant — Volga HEP im. Lenin — was commissioned. All the 20 turbines of this plant were built at LMZ. These turbines each develop a power of 126,000 kw with a head of 22.5 m, and have high efficiency (up to 94%) (see Figure 64).

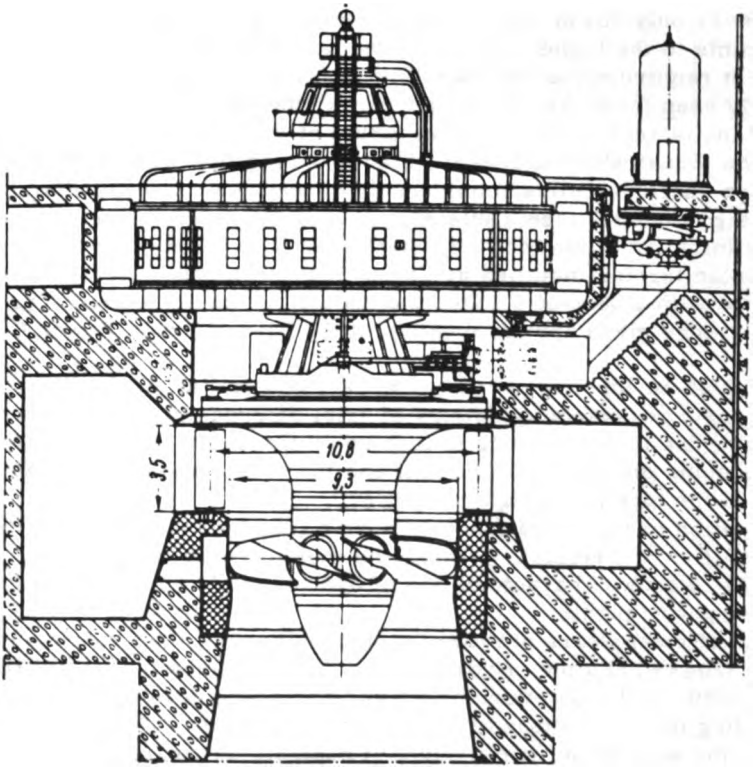

FIGURE 64. The world's largest Kaplan turbine at Volga HEP im. Lenin

The power of a single turbine of the Volga HEP considerably exceeds the total power of the first Soviet hydroelectric plant, Volkhov HEP im. Lenin. The water discharge through a turbine at the Volga Plant reaches 700 m^3/sec — half the mean discharge of the Oka River, a tributary of the Volga. More than 2 million m^3 of water pass through each turbine per hour — an amount corresponding to the volume of a storage lake with a surface of 1 km^2 and a depth of 2 m.

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The runner diameter is 9.3 m. The distance between a runner blade and the top of the generator is 20 m. The diameter of the turbine speed ring (stator) is 17.5 m. The height of the turboalternator is thus roughly that of a seven-story house.

The rotational speed of the runner is relatively low, 68.2 rpm, but the peripheral velocity of the generator rotor reaches 180 km/hr. The weight of the turbine runner is 426 tons; each blade weighs 20 tons. The 130 Mw generator has an impressive weight, 1600 tons. The rotor has a diameter of 14.3 m and a weight of 650 tons. The generator has an efficiency of 97.4%. The total height of the turbogenerator is 40 m and its weight is more than 3000 tons. The shafts of the unit were forged from 180 tons ingots.

The first of the 20 turbines was built at LMZ in 1954. All the turbines were completed within three years (1954-1957).

With a runner diameter exceeding that of the prewar Uglich and Rybinsk turbines by only 30 cm, the Volga turbine produces almost double the power. This points to the higher loadings used in the Volga turbine, and the more stringent requirements that had to be observed regarding reliability. This is easily seen from the following figures: the centrifugal force acting in each blade is 1400 tons; the axial thrust of the water on the runner is 1500 tons; the thrust which drives the blades during operation is 2340 tons.

These characteristics considerably exceed the corresponding figures for foreign turbines (see Table 30). Thus, the largest foreign Kaplan turbine installed at the McNairy Station (U.S.A.)[43] is rated at 101.5 Mw. The Kaplan turbine installed at Varon HEP in Sweden develops a power of 14,200 kw with a head of 6.15 m; the runner diameter is 8 m. The Soviet turbines were given special mention at the Vienna World Power Conference (1956).

The LMZ turbine unit is very compact despite its large size. The design ensures perfect symmetry of axial stresses in the load-carrying elements; the thrust bearing is located on the cover plate of the turbine, thus reducing the weight of the unit and the shaft length (13.8 m as against 18.7 m in the turbines of Rybinsk HEP).

Operation of the Volga turbines over a long period has shown their high qualities and reliability under the most diverse conditions.

Table 29 shows characteristics of hydroelectric equipment installed at Soviet power plants.

In the thirteen years between the manufacture of the first Soviet Kaplan turbine (294 kw) and the creation of the giant turbines for Volga HEP im. Lenin (1930-1953) Soviet scientists and engineers developed a theory for calculating the dimensions of axial turbine runners. This theory, in conjunction with model tests, made it possible to create a series of Kaplan runners of various specific speeds for a range of heads from 3-4 to 40-45 m. These runners give turbines high efficiency and good resistance to cavitation. Other elements of the water passages, spiral casing, draft tube, runner casing, distributor (guide ring) and stator (speed ring), governor, etc. were redesigned and improved. As a result of these improvements the cost of producing the twentieth turbine was a third less than that of the first.

Table 30 presents data on Kaplan turbines produced during this period.

As stated above, one of the most important problems that faced Soviet turbine builders was to reduce weight while raising efficiency.

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TABLE 29

Kaplan turbines installed at various power plants

HEP	Head, m		Turbine power, Mw	Rpm	Runner diameter, m	Discharge through turbine, m^3/sec	Turbine weight, tons	Generator weight, tons
	maximum	rated						
Ivankovo	17.5	13.0	15	100	5.0	135	346	350
Uglich	14.5	13.2	53	62.5	9.0	482	1300	1200
Rybinsk	20.0	13.2	53	62.5	9.0	600	1300	1200
Gorki	18.0	12.2	57.2	62.5	9.0	585	1160	1080
Volga HEP im. Lenin	30.0	20.0 (22.5)	115 (126)	68.2	9.3	670	1500	1650
Volga HEP im. XXII Congress of the CPSU	27.0	20.0	115	68.2	9.3	670	1430	1420
Saratov	17.0	9.25	56	50.0	10.3	795	1500	1070
Perm	21.0	15.0	21.8	125.0	5.0	172	285	264
Votkinsk	23.2	16.5	100.0	62.5	9.3	710	1177	1300

TABLE 30

Comparison of Soviet and foreign Kaplan turbines

HEP	Turbine power, Mw	Head, m	Runner diameter, m
Volga HEP im. Lenin	126	22.5	9.3
Ice Harbor, U.S.A. (design)	107	27.2	7.2
McNairy, U.S.A.	101.5	26.0	7.1
Votkinsk	100	23.2	9.3
Dallas, U.S.A.	95	24.3	7.15
Orlik, Czechoslovakia	90	71.5	4.6
Irkutsk	90	26	7.2
Ligga (Sweden)	78	40.5	5.5
Rybinsk	65	13.2	9.0
Lasele, Sweden	62	54	4.8
Saratov (design)	56	17	10.3
Slapy [Vltava], Czechoslovakia	51	56	3.7
Kakhovka	51.8	13.8	8.0
Tsimlyanskaya	41.5	17.5	6.6
Beaurieux, France	23(15)	70(80)	—
Perm	21.8	21	5.0*
Invergarry, Scotland	20.5	55	2.9
Himekawa, Japan	20.5	55	2.9
Argentat, France	14.7	16.8	—
Varon, Sweden	14.2	6.15	8.0
Nambia, Italy	13.5	88.4**	—

* Vertical turbines; for the trial semitubular turbine the runner diameter will be 10% larger.

** Maximum head for Kaplan turbine.

The turbine for Kakhovka HEP has an 8 m runner and weighs 1050 tons, while the turbine of Volga HEP im. Lenin, with a larger runner (9,3 m), weighs 1500 tons.

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Thanks to improved design and the use of better materials and processes (e.g., welding) turbine-building plants achieved a marked reduction in the weight (kg/kw) of turbines (see Figure 65). Thus, using a welded stator instead of a cast one (turbines for Pavlovsk, Kakhovka and Novosibirsk HEPs) reduced turbine weight by up to 30 tons.

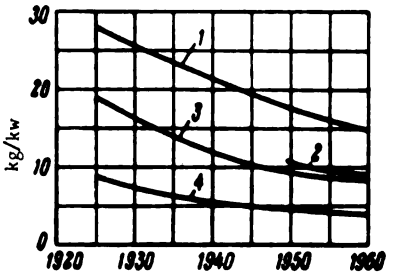

FIGURE 65. Reduction in weight of turbines of different type, kg/kw

1—Kaplan for heads of up to 20 m; 2—Kaplan for heads of 25-40 m; 3 — Francis for heads of 30-60 m; 4 — Francis for heads of 70-300 m.

Turbine efficiency was steadily improving. The guaranteed efficiency of the Volga turbines is 94% (under optimum operating conditions), whereas foreign manufacturers did not guarantee an efficiency higher than 93%[44].

The higher turbine efficiency means that Volga HEP im. Lenin and Volga HEP im. XXII Congress of the CPSU can both produce about 40 Mw more power.

The new turbines have excellent hydraulic characteristics that permit minimum depth for the powerhouse foundation, it being well known that a reduction in depth of even one meter yields savings of tens of millions of rubles.

Figure 66 clearly shows the progress made in Soviet turbine construction (Francis type). The height of units has been gradually reduced by installing the thrust bearing directly on the turbine cover plate. In earlier designs of Francis turbines the ratio of turbine height (measured from the hub extension to the top of the generator) to the runner diameter (L/D) varied from 3.5 to 4.2. This ratio has dropped to 2.6-2.7. Shaft lengths have decreased correspondingly, as have the amount of metal used and investment costs. These improvements were needed to permit the use of the new combined (built-in) layout of power stations — a development first used in the USSR.

Figure 66,b shows how the layout of turbogenerators has improved. At Rybinsk HEP, the height of a turbogenerator was 29.5 m, and D = 3.28 m. The height of the Volga HEP im. Lenin turbogenerator was only 26.57 m, with D = 2.85 m. Another turbogenerator [apparently at the same plant] with electronic excitation has a height of 25.46 m, with D = 2.72 m. The height of the Saratov HEP turbogenerator is 24.01 m, with D = 2.66 m; the turbogenerator has a single shaft.

The most important development trends in Soviet turbine construction are: an increase in the unit power of turbines, and the construction of high-speed turbines for high heads.

Since 1957 LMZ has designed and constructed 250 turbines of various standard sizes, totalling more than 6 million kw. A further 4500 turbine units (of smaller sizes) totalling 1 million kw were built at other plants. In the postwar period, there has been a pronounced tendency to increase the unit power of turbine sets. This is seen from the following figures (Figure 74): during the period from 1924-1928, the average unit power of turbine sets was 490 kw; in 1928-1932 (second Five-Year Plan) it was 2500 kw; in the period 1933-1937 it reached 6400 kw; during the next

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Five-Year Plan period the power went up to 26,200 kw, and during the time of the fourth postwar plan, it rose to 51,000 kw. During the fifth Five-Year Plan period, unit powers reached the unprecedented value of 126 Mw at Volga HEP im. Lenin).

The rated power of the Volga HEP turbogenerators was 105 Mw. They proved able to supply 126 Mw. It thus became possible to reduce the total number of units (initial figure 20) without reducing the installed capacity. This, of course, led to considerable savings.

With the increase in the unit power of the turbines, it became possible to reduce the length per megawatt of the powerhouse (Table 31).

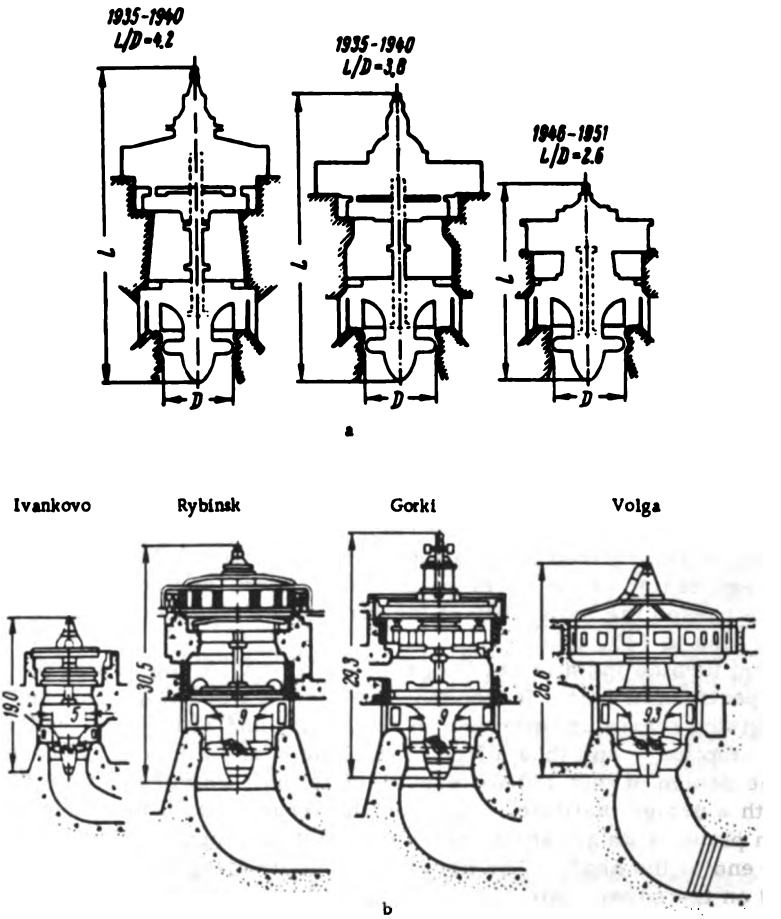

FIGURE 66. Changes in layout and size of Kaplan turbines

a—development of layout, 1935—1951; b—comparison of turbines. Ivankovo—P = 15 Mw, H = 13 m; Rybinsk—P = 53 Mw, H = 13.2 m; Gorki—P = 57.2 Mw, H = 12.2 m; Volga—P = 105 Mw, H = 19 m.

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TABLE 31

Reduction in length per megawatt of powerhouses with increase in unit power of turboalternators

HEP	Length per megawatt, m	HEP	Length per megawatt, m
Volkhov	2.3	Novosibirsk	0.44
Rybinsk	0.7	Bratsk	0.115
Kakhovka	0.5	Krasnoyarsk	0.074
Kremenchug ...	0.5		

The continuous growth in the unit power of turboalternators has been reflected in an increase in the size of the turbines. Thus, the Francis turbines for Volga HEP have runners with a diameter of 9.3 m; the diameter of the speed ring, the largest single component of the turbine, is 14 m. The Saratov turbines each have a power of from 200 Mw to 250 Mw; the runner diameter is still larger — 10.3 m. The water discharge through these turbines is 800 m^3/sec. The plans for this turbine which has unprecendented features in its design, were completed ahead of schedule.

The construction of large turbines creates complex problems: special machining equipment and transportation facilities are necessary. These factors are interdependent; they continuously act to stimulate improvement in turbine design. This is seen from the following: the turbines built for Volga HEP im. Lenin during 1950-1053, are much larger than those built for the Rybinsk and Uglich HEPs. Twenty-one similar turbines were installed at Volga HEP im. XXII Congress of the CPSU. This type will also be installed at other plants.

The turbines for Volga HEP im. XXII Congress of the CPSU do not differ basically from those for the Volga HEP im. Lenin; the former incorporate the latest developments in engineering. Some features of the new turbines deserve mention: the location of the thrust bearing on the cover plate of the turbine, a special slide valve for emergency closing of the distributor, an all-welded speed ring, greater use of welding, connections, a centralized lubrication system for the whole turbogenerator, and improved design of the cover plate, distributor, and runner. These changes increased the reliability of the turbine and reduced its weight from 1500 tons to 1430 tons.

The 22nd turbine installed at Volga HEP im. XXII Congress of the CPSU was an experimental unit. It incorporates a series of design changes aimed at giving maximum increase in reliability and efficiency, reduced steel consumption — and thus a lighter-turbine — and a shorter construction time. The design of this 150 Mw experimental unit was drawn up by LMZ jointly with a design institute. This turbogenerator has a more rigid foundation plate, a single shaft, and a compact oil-supply unit located at the upper end of the shaft. The servomotor controlling the distributor is located on the cover plate of the turbine; the runner blades rotate in rolling-type bearings. A weight reduction of 460 tons was achieved, compared with the series-produced units (16%); the height was similarly reduced by 4.2 m. Water cooling of the generator windings made possible a power increase of 30%, without any increase in size or changes in the excitation system.

The experimental unit was installed in 1962.

There is an ever-increasing trend to widen the range of application of Kaplan and Francis turbines.

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Kaplan turbines now built in the USSR for heads varying from 5 to 40 m, have an efficiency of up to 94%. Francis turbines used for larger heads (from 40 to 300 m) have a slightly lower efficiency (up to 93%), while Pelton turbines are used for heads of up to 430 m (e.g., at Khrami HEP)[45] and have an efficiency of 90-91%. An increase in the maximum head for Kaplan turbines means that in a certain range of head they can displace turbines of lower efficiency. The output of electricity is thus raised.

With higher heads the specific speed of Francis turbines drops. However, during the early period of power development in the USSR, Francis turbines were the prevailing type[46].

In the USSR the maximum head at which Kaplan turbines are used is 35 m; abroad Kaplan turbines are used for heads of up to 88 m[47]. The superiority of Kaplan turbines over Francis units (for the same head) is evident from the following considerations.

The increasing interconnection of power plants in the USSR means that hydroelectric plants are bound to play an important role in coping with load fluctuations. Kaplan turbines are most suitable for such duty as they can be more flexibly controlled (double regulation). Soviet design agencies, being fully aware of these advantages, are now designing units for heads in the range of 75-80 m. This is by no means the limit. Kaplan turbines for heads of up to 100 m are apparently being designed. All this will increase the unit power of these turbines to 200-300 Mw. A problem of some economic importance is the reduction of the high metal requirements of Kaplan-turbine construction.

Research institutes are working on these problems, improving methods of designing the water passages of turbines, and developing methods for investigating flow and pressure distribution in water passages.

Not only Kaplan turbines are suitable for turbine high heads; variants such as the diagonal [Dériaz] turbine can be used. In this type the axis of blade feathering is inclined to the axis of rotation of the shaft.

Dériaz turbines and radial-axial turbines with adjustable blades, although developed in the USSR as early as 1950[48], did not gain wide acceptance in the USSR[49].

For heads in the range 70-120 m, these turbines may be used successfully in place of Francis turbines; higher power, speed, and efficiency are thus achieved. These turbines have the remarkable property of maintaining their high efficiency and reliability during considerable variations of head and load. Higher drawdown of the storage reservoir and hence higher output are thus possible.

An improved version of the Dériaz turbine for heads in the range 50-90 m is now in the design stage. It will be used at Bukhtarma HEP and many other Soviet plants.

Horizontal turbines with straight draft tubes are of great interest, in that they permit simpler design and better layout of powerhouses. Such turbines are particularly suitable for large lowland-river plants operating with low heads (6-20 m). In such power stations horizontal turbines require a smaller excavation depth for the powerhouse. The basic advantage of horizontal turbines compared with the vertical type is their higher efficiency and power (2-7% and 15-40%, respectively). This is of

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particular importance with lowland-river plants, which are usually equipped with units of high [specific] speed.

LMZ has mastered the production of horizontal turbines for 6-20 Mw. These turbines may conveniently be located in the dam piers. This considerably reduces the dam frontage.

A horizontal tubular turbine operates successfully at Ortochaly HEP (in Georgia) with a head of 10.5 m. The turbine, which has a 3.3 m runner, develops 6300 kw. The generator rotor is connected to the runner shroud ring. The runner blades are adjustable and the blade-adjusting mechanism, together with its hydraulic servomotor, is housed in the runner. The fastening of the generator rotor to the runner is, however, a procedure involving very considerable engineering problems.

In 1958, LMZ designed and installed at Kama HEP an experimental turbine of horizontal semitubular type. With a head of 21 m, a power of 21,800 kw is developed; the runner diameter is 4.5 m. In this turbine the generator is installed in a special compartment [bulb] in front of the turbine, as mentioned above. In tubular turbines the runner carries the rotor. This makes it particularly difficult to prevent water penetration to the windings. This disadvantage does not exist with semitubular turbines, while the advantages of tubular turbines are preserved. Further, the design is much simpler.

The runner diameter of this semitubular unit is 0.5 m less than that of the vertical turbines at Perm HEP, but the power developed is the same — 21,800 kw. The efficiency is 1.5% higher, and the weight is less than that of the vertical units. Water is fed to the semitubular unit through two inclined lateral channels, which unite to form a single water conduit. This leads into the spiral casing.

Semitubular turbines give 20% more power than vertical Kaplan turbines. If semitubular turbines had been used at Perm HEP, it would have been possible to keep the number of sets down to four.

Khar'kov Turbogenerator Plant (KhTGZ) is starting to build turbines for Dneprodzerzhinsk HEP (runner diameter 9.3 m, head 9 m), and bulb-type units for Kiev HEP.

The larger water-rich rivers of Siberia are characterized by large differences of level (head). To exploit this situation it is necessary to design more efficient Francis turbines for heads of about 100 m.

The construction of such large turbines is not easy, as they require runners with diameters of at least 6 m. Particular attention should therefore be given to problems of strength, power generation, and cavitation. The factors involved here are often mutually conflicting. It is not surprising that much importance is attached to research. During the early period of power construction in the USSR, the role of the designer was the dominant one. The picture is now being reversed: more research workers are engaged in turbine construction than designers. A great number of Soviet research agencies are dealing with problems of turbine construction, e.g., the Institute of Machine Building at the Academy of Sciencies of the USSR, TsNITMASh, the All-Union Institute for the Construction of Hydraulic Machinery, the Welding Institute im. Paton, Kiev, the Khar'kov Polytechnic Institute, etc.

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With the experience they have gained in the design and construction of large turbines, Soviet constructors are able to tackle the construction of very large turbogenerators for the power plants of the future Unified Power System. In this connection, the installation of large hydraulic turbines is particularly effective; for example, if a large thermal power station sheds its load, the load can easily be sustained by hydraulic turbines. This ensures stability of frequency and operation.

In 1960 LMZ, in cooperation with Elektrosila Works, manufactured a 230 Mw experimental Francis turbine for Bratsk HEP. The first stage of this station was commissioned at the end of 1961, much ahead of schedule. The unit is intended for operation with a rated head of 96 m (maximum 102 m, minimum 92 m). Under such conditions, a Francis turbine is much cheaper than an equivalent Kaplan turbine. The diameter of the runner is only 5.5 m, and its speed of rotation only 125 rpm. Still more important, this turbine, with double the power of the Volga turbine, weighs only about 800 tons — half that of the Volga turbine. This turbine is unique in design and power rating[50] (see Figure 74).

A party of American senators, after a visit to the USSR, had to recognize the fact that Soviet hydropower plants are equipped with larger turbines than those found in American plants. The largest turbines in the U.S.A. (108 Mw) are installed at the Grand Coulee Plant, while the USSR already has in operation 115 Mw hydraulic turbines. For Bratsk HEP 225 Mw turbines are to be manufactured, and for Krasnoyarsk HEP still larger units (up to 500 Mw).

As mentioned above, the creation of these giant turbines poses many difficult engineering problems: reducing runner sizes, improving the design of spiral casings, raising rotational speeds, etc.

Using the results of research and experiments, LMZ is now designing a Francis turbine for Krasnoyarsk HEP to develop 508 Mw with a head of 95 m. The water discharge is 580 m^3/sec, the runner diameter 7.5 m, and the rotational speed 93.8 rpm. The draft height of the turbine is extremely low; the efficiency reaches 94%. The capacity of this turbine is nearly equivalent to the installed capacity of the famous Dnieper HEP. Each of these new turbines gives savings of up to 300 tons of metal. It was initially intended to install 18 units at this station, each rated at 300 Mw. It is now intended to install only ten units of higher rating.

It now seems likely that Francis turbines of 750-1000 Mw will be built. Such turbines would be installed in Siberia and the Far East for still higher heads of 150-200 m. As already mentioned, the plan for Krasnoyarsk HEP provides for the installation of ten 500 Mw units to give 5000 Mw with a head of 100 m (Figure 67). The railroad transportation of a huge 7.5 m runner necessitates its being made up of parts which are assembled on site, and held together by special shroud rings. An alternative would have been to build the turbine with a twin runner. Because of the high head, the construction of a steel or concrete spiral casing, with a diameter of up to 10 m, is also a difficult problem.

The generator for this giant turbine underwent radical design changes. The windings were redesigned to have internal cooling of both the stator and rotor. Such generators were first designed in the USSR; they have not yet been built abroad.

The Khar'kov turbogenerator plant has completed the plans for the construction of the world's largest Francis turbine, which will have

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a higher speed than any other Francis turbine. The unit will have a power of 310 Mw, and is intended for Nurek HEP. The head will be greater than 200 m.

A problem which has recently arisen is the erosion of turbine elements due to the large amount of solid load carried by some mountain rivers. As an example, Vakhs River transports up to 25 kg of quartz particles per cubic meter.

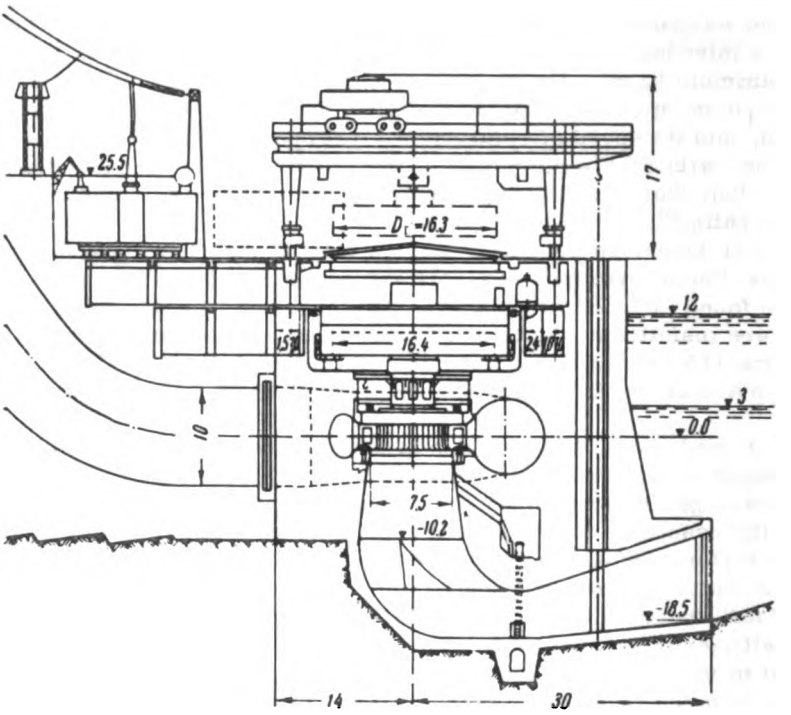

FIGURE 67. The 500 Mw turbine unit of Krasnoyarsk HEP

Increasing the specific speed of turbines leads to an increase in the erosion of the turbine elements. The steps taken are to use wear-resistant materials, to reduce speed, and increase turbine dimensions. Thus, at Perepadnaya HEP on the Vakhsh River, special low-speed turbines have been installed in place of the high-speed Francis turbines. As a result of the lower velocity of water flow, which decreased by 40-50 %, the rate of wear dropped considerably.

More and more importance is being given to improving the design of main and auxiliary equipment. New ways are being sought to improve the hydraulic properties of turbines and the arrangement of the elements of the turbine unit so as to obtain more economic layouts[51]. The development of the new types of turbine (counter-rotating, Dériaz, tubular, etc.) should be pushed ahead, and the established types should be further improved.

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Although attention has been focused mainly on hydraulic turbines, the construction of other electrical equipment (generators, transformers, etc.) has not been neglected. Elektrosila, KhTGZ, and other plants have designed high-quality generators of 50, 100, 150, and 200 Mw, which are as good as the most up-to-date equipment designed abroad (Figure 74).

Soviet industry supplies modern equipment to the ever-expanding power-construction industry in the USSR, to the countries of the people's democracies, and to underdeveloped areas (India, Egypt, Guinea, etc.).

NOTES

[1]Khrushchev, N.S. Povyshenie blagosostoyaniya naroda i zadachi dal'neishego uvelicheniya proizvodstva sel'skokhozyaistvennykh produktov. Rech'na Plenume TsK KPSS 17 yanvarya 1961 (Raising Living Standards by Raising Agricultural Production. Address to Plenary Session of the CC CPSU, 17 January, 1961).—Gospolitizdat, p.24. 1961.

[2]E.g., a statement by the chief editor of the West German periodical Deutsche Elektrotechnik was quoted in Elektrichestvo, No. 11, p.47. 1957.

[3]Nesteruk, F. Professor Fedor Grigor'evich Zbrozhek.— "Rechnoi transport", No. 5. 1962.

[4]Nesteruk, F. Iskusstvennye vodokhranilishcha mira (Artificial Storage Lakes of the World).— Gidrotekhnicheskoe stroilet'stvo, No. 4. 1946.

[5]Chaplygin, S. Nikolai Nikolaevich Pavlovskii.— Vestnik AN SSSR, No. 6, p.66. 1937.

[6]In the EHDA method, pervious soil is simulated by a conducting medium (an electrolyte, a thin metal sheet, graphite powder, etc.) and the streamflow by an electric current.

[7]See: Aleksandrov, B.K. Proektirovanie gidroelektrostantsii (skhema ispol'zovaniya Volgi) (Design of Hydroelectric Power Stations (The Volga Power Scheme)), p.44, Moskva-Leningrad. 1955.

[8]Nesteruk, F. Beton i betonnnoe khozyaistvo gidrotekhnicheskikh sooruzhenii (Concrete and Concrete Mixing for Hydrotechnical Structures). Moskva-Leningrad. 1941.

[9]A "two-tier" dam is a water-retaining structure in which the overflow spillways and sluiceways are located in a single section of the dam. This gives savings in the stilling elements in the tailwater. During the construction period (erection of the dam), the sluiceways discharge the normal streamflow, while in normal operation they are used for the discharge of flood water.

[10]According to available data on large dams of the world, of 1300 dams with a height greater than 30 m, about 70% are concrete dams, 25% of earthfill type, and only 5% of rock-fill type. Of the concrete dams,

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70% are of gravity type, and 30% are light-weight (arch, buttress types and dome). There is an increasing trend to build earthfill dams made of locally available cheap soil, instead of concrete gravity dams.

[11]With wide expansion joints up to 3-5 m (e.g., Oberaar, Reteikhsboden, and Albinen dams in Switzerland) savings in concrete amounted to 14%, compared with classical concrete dams. Wasser und Energiewirtschaft, Bd. 48, Nos. 7-9. 1956.

[12]Nesteruk, F. 12-letnii opyt stroitel'stva plotin Netsli (Twelve Years Experience in the Construction of Noelzli Dams).— Gidrotekhnicheskoe Stroitel'stvo, No. 12. 1946; idem. Razvitie gidroenergeticheskogo stroitel'stva v KNR (Development of Hydropower Construction in the People's Republic of China).

[13]A wealth of information and data on arch dams in Europe and America may be found in the Journal of the Power Division, Proceedings of the American Society of Civil Engineers, No. 82, April. 1956.

[14]The highest gravity dam in the world, Grand Dixence Dam, height 284 m, length 700 m, has a volume of 5.95 million m^3, i.e., three times the volume of Inguri Dam (Hoch und Tiefbau, l'Enterprise, Bd. 60, No. 39. 1961).

[15]Gausman, K. Istoricheskii ocherk gidrotekhnicheskikh sooruzhenii Sestroretskogo oruzheinogo zavoda s 1721 po 1840 (History of the Hydrotechnical Structures of Sestroretsk Arsenal).— Inzhenernyi Zhurnal, No. 2, p. 123. 1861.

[16]The highest earth dams in the world are: the wide-core Trinity Dam in the U.S.A. (height 164 m, length 750 m, volume 21.2 million m^3); the thin-core Göschenenalp Dam in Switzerland (height 155 m, length 540 m, volume 8.3 million m^3), which is filled with coarse-grained material; Swift Dam in the U.S.A. (height 153.5 m, length 600 m, volume 12 million m^3). See also Nesteruk, F, Velichaishie zemlyanye plotiny mira (The Highest Earth Dams of the World).— Gidrotekhnicheskoe stroitel'stvo, No. 10, p. 27. 1946.

[17]The oldest type of water-retaining structures are rock-fill dams. A dam of this type, believed to have been erected about 5000 B.C., may be seen 30 km from Cairo. It consists of two parallel masonry dikes, 36 m from each other, the space between being filled with river stones and earth filling. The dam has a height of 12 m, and 1:1.25 gradients.

[18]An earthfill dam with a watertight facing made of plastics is mentioned in a foreign publication (Tolke, Talsperren [Barrages], Berlin. 1953). In hydrotechnical structures, plastics are used to enhance the properties of conventional materials. The watertightness of dams may be increased by resin facings which penetrate slightly into the soil [of which they are made]. Concrete structures may be made watertight by coating them with thin plastic films or impregnating them with resins. There have also been dams made entirely of synthetic materials (Nesteruk, F. Plotina iz neilona (A Nylon Dam)).—Rechnoi transport, No. 12. 1960).

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[19]The number of rockfill dams being built abroad is increasing. Such are Goschenenalp in Switzerland (155 m high), Miboro in Japan (130 m high), Trausglet in Sweden (122 m high), Brownlee in the U.S.A. (122 m high). Mica Creek (213 m high) is in the design stage.

[20]The largest foreign earthfill dams have been built in the U.S.A: the Fort Peck Dam (volume 95 million m^3, height 83 m, length 2700 m); the Oahe rolled earthfill dam (volume 60 million m^3, height 74 m); and the Garrison Dam (volume 53 million m^3, height 64 m).

[21]For the construction of Mingechaur Dam, the material was taken from a borrow pit and transported in trucks to the site, where it was mixed with water and applied with a water giant. Although no slurry pipeline was used, as with other dams, the dam should nevertheless be considered a true earthfill dam.

[22]The construction rate of dry-filled earth dams is not slower than that of hydraulically filled dams: 100,000 m^3/24 hours at Fort Peck Dam, against 155,000 and 153,000 m^3/24 hours at Anderson Ranch and Garrison dams. In the construction of Kuibyshev Dam, the rate of filling reached 300,000 m^3/24 hours.

[23]Ejection is the reduction in pressure in the draft tube; it acts to increase power during high water (particularly on lowland rivers), counteracting the power loss due to the rise in level of the tailwater in relation to the headwater.

[24]In a number of recent hydroelectric projects, the powerhouse was separate from the dam (behind the dam in the headwater section), with the water-intake tubes installed within the dam body . The flood water is discharged over the massive deck of the powerhouse. An upturned bucket suitable for the free overflow of the water is built. Nesteruk, F. Noveishee gidroenergostroitel'stvo Frantsii (Recent Advances in France in Hydropower Construction).— Gidrotekhnicheskoe stroitel'stvo, No. 8. 1946.

[25]Data on and drawings of the Volga fish lift were put at our disposal by A.M. Rumyantsev, engineer, of the Water-Management Committee of the Council of Ministers of the RSFSR.

[26]Lenin, V.I. Sochineniya (Works), Vol. 31, p. 427.

[27]See Pravda, 2 December, 1959, for relevant quotations from the American newspaper "Star".

[28]Cf. Plan elektrifikatsii RSFSR (Electrification Plan for the RSFSR), p. 20, Moskva. 1920.

[29]Gidromashinostroenie (Construction of Hydraulic Machinery). Collection of papers by members of the Faculty of Hydraulics and Hydraulic Machinery of MVTU, p. 3, Moskva. 1949.

[30]The first axial propeller-type turbine built in the USSR was designed and tested by Professor G.F. Proskura at the hydraulics laboratory of the Khar'kov Technologic Institute in the period 1922-1923. (Cf. Sbornik trudov laboratorii problem bystrokhodnykh mashin i mekhanizmov).—Izdatel'stvo, AN SSSR, Vol. 3. 1953.

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[31]See Table 1.

[32]Smirnov, M. Avtomaticheskie regulyatory protechnogo tipa (Automatic Flow-Type Regulators). Moskva-Leningrad. 1938.

[33]For the turbines of ZAGES HEP, Leningrad Metal Works improved the design of the blade-adjusting mechanism. Their system replaced the conventional system used by the Swedish plant, Werkstaden, at Lower-Svir HEP and ZAGES No. 2. HEP. The Swedish blade-adjusting mechanism involved the use of slide blocks and a complicated mechanism. The improved design of LMZ dispensed with these parts and used a crankshaft drive instead. This idea was subsequently incorporated in a great number of Soviet-built blade-adjusting systems. Cf. Time, V. Mekhanizmy povorota lopastei konstruktsii LMZ (LMZ Blade-Adjusting Mechanism).— Kotloturbina, Sbornik No. 2., Leningrad. 1933.

[34]Soviet achievement in this field at that time can be judged by the fact that high-head Kaplan turbines (22-25 m) had been installed at only three stations: Grenvolfors, Norway; Wettingen, Switzerland; and Shannon, Ireland; (see Nesteruk, F. Gidroenergetika mira (Hydropower Engineering Projects of the World)), p. 104, Moskva-Leningrad. 1946.

[35]Malyshev, M. Turbina Nizhne-Svirskoi GES (The Turbine for Lower-Svir' HEP).—Byulleten Svir'stroya, Nos. 17-18. 1939.

[36]Smirnov, M. Regulyatory gidroturbin kanala Moskva-Volga (Governors for the Hydraulic Turbines of the Volga-Moskva Canal).— Sovetskoe kotloturbostroenie, No. 1. 1938.

[37]Redesign of the turbines installed at Uglich HEP, carried out after the war, gave savings in metal of 120 tons. Several such redesigned turbines were built for Rybinsk HEP by LMZ.

[38]The American turbines had poor characteristics: their efficiency did not exceed 90.5%. Another serious drawback of these turbines was hydraulic shock (water hammer) in the draft tubes; they also suffered from vibrations.

[39]Kovalev, N., et al. Novye turbiny dlya Dneprovskoi GES (New Turbine Designs for Dnieper HEP).— Mashgiz. 1951.

[40]The new American turbines delivered to Dnieper HEP after the war had a coefficient of 6.2 kg/kw.

[41]The accuracy of regulation of the old American turbines was 0.5%.

[42]The maximum head of Francis turbines in the USSR is 285 m; abroad they are found with heads up to 543 m (Hemsill HEP in Norway). In July, 1961, LMZ completed the construction of the turbine for the Khrami No. 2 HEP. This turbine operates at 428 rpm, with a head of 324 m.

[43]For Ice Harbor HEP (U.S.A.) the Morgan-Smith Company designed 107 Mw Kaplan turbines for a head of 27.2 m; runner diameter 7.2 m, speed 90 rpm.

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[44]Maximum efficiencies for foreign turbines (according to data presented to the World Power Conference in Vienna in 1956) were: for Kaplan turbines 93%; for Francis turbines 92%; and for Pelton turbines 91%.

[45]It is interesting to note that a turbine at Reisseck-Kreuzeck, Austria, operates with the world-record head of 1773 m.

[46]It is intended to replace the Francis turbines at Volkhov HEP with Kaplan units.

[47]A power plant in Nembia, Italy, has Kaplan turbines operating with a head of 88.4 m.

[48]Kvyatkovskii, V. Dve novye sistemy reaktivnykh povorotno-lopastnykh gidroturbin (Two New Types of Kaplan Turbines).— Gidrotekhnicheskoe stroitel'stvo, No. 11, p. 62. 1957.

[49]Much later Dériaz turbines were developed abroad. They were used in a pumped-storage scheme (Sir Adam Beck No. 2 Station, Niagara). At the XII Session of the World Power Conference in 1958, it was rightly noted that Dériaz turbines represent the greatest step forward in hydraulic-turbine construction since the invention of the Kaplan turbine (General Report to the World Power Conference, Montreal. 1958).

[50]The unit power of similar Francis turbines abroad has reached only 195 Mw for a maximum head of 195 m (the underground station at Chute de Passe, Canada); for a head of 165 m, the unit power of Francis turbines abroad has reached 147 Mw. In 1962, the Furnace HEP in Brazil was equipped with 168 Mw Francis turbines, manufactured by the Swedish company, Nydgvist and Holm.

[51]A new turbine type, the so-called "Sphindex" turbine, has appeared abroad. Turbines of this type have smaller overall size, and their use results in smaller powerhouses. The new type has better characteristics than Francis turbines but is inferior to Kaplan units. An area of application for such turbines seems to be at high-head (350-400 m) plants on mountain rivers.

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Chapter VII

SOVIET FOREIGN ASSISTANCE IN POWER CONSTRUCTION

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The ideas and principles embodied in the GOELRO Plan were translated into fact a few decades later. The GOELRO Plan is also of great international significance. Lenin stressed that the GOELRO Plan demonstrates "to the whole world the positive approach of the [Socialist] construction industry"[1].

Today, the GOELRO Plan is used as a guide by the countries of the people's democracies in their ambitious power-construction programs.

The reconstruction and rapid expansion of the economies of these countries made it imperative to devote more attention to power construction (see Table 32 and Figure 68).

In 1960 the USSR produced 292 billion kwhr; the European countries of the people's democracies produced 114 billion kwhr, against 24.5 billion kwhr prior to the war.

Bulgarian People's Republic. In prewar Bulgaria, power engineering and construction was one of the most backward branches of the economy[2].

After the liberation of Bulgaria in 1944, power construction continued to lag behind other industrial branches. Bulgaria's annual waterpower potential is evaluated at 10-11 billion kwhr (excluding the Danube). More than 80% of these resources are in southern Bulgaria.

The year 1950 was a turning point — in that year a start was made on the exploitation of Bulgaria's large power resources. Stress was laid on the construction of cascade power plants on rivers. The share of hydropower in the total Bulgarian power supply is quickly increasing: by the end of 1950, hydropower already accounted for 33.5% of the total power generated.

At present the total capacity of Bulgaria's power stations is 521 Mw, with a yearly output of 1687 million kwhr. Five plants are under construction; their total capacity will be 342 Mw.

The largest project is a cascade scheme on the Batak-Aleko River, which uses a total head of 1284 m. The scheme consists of three plants with a total capacity of 220 Mw (605 million kwhr annually). Of these three plants, the 120 Mw Peshtera Plant — the largest in Bulgaria — was commissioned in 1959. Its power exceeds Bulgaria's total prewar installed capacity.

Today, Bulgaria has a unified power system. About 80% of the population lives in localities where electricity is available.

In terms of power production, Bulgaria is far ahead of her Balkan neighbors — Greece and Turkey. In 1960, the total output in Bulgaria was 4650 million kwhr. Yearly per-capita consumption is now 600 kwhr, against 42 kwhr in 1939. More than 4250 villages have been connected to electric networks.

To quote Stefan Nikolov, chief engineer of Energoproekt, Bulgaria: "The successes obtained in Bulgaria in the field of power construction would have been unthinkable without generous help from the USSR. Aid from

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TABLE 32

Power generation in the countries of the people's democracies (billion kwhr/year)

Country \ Year	Prewar	1950	1952	1955	1956	1957	1958	1959	1960	Share of hydropower in the total power supply, %
Bulgarian People's Republic . .	0.266 (0.153) (1939))	0.797 (0.267)	1.35	2.07 (0.648)	2.39	2.65 (0.83)	3.02 (0.95)	3.87 (1.10)	4.65	31.5
Hungarian People's Republic . .	1.4	3.0	4.19	5.43	5.20	5.45	6.48	7.09	7.6	0.8
East German Democratic Republic	14.0*	19.47	23.18	28.69 (0.50)	31.18 (0.52)	32.73 (0.48)	34.87	37.23 (0.53)	40.3	1.8
North Vietnam Democratic Republic	0.122 (1939)	—	—	0.053	0.094	0.121	0.160	0.208	0.25	—
North Korean People's Republic .	8.14	4.58	1.44	3.14	5.12	6.91	7.63	7.81	9.1	>90
Chinese People's Republic	5.95	4.55	7.26	12.27	16.659	19.03	27.5	41.5	55.5**	18.4
Mongolian People's Republic . . .	0.014	0.16	0.023	—	0.04	0.051	0.085	—	0.085	—
Polish People's Republic	3.63	9.42	11.98	17.75	19.49	21.15	23.96	26.38	29.2	2.1
Rumanian People's Republic . . .	1.13 (0.15) (1938)	2.11 (0.17)	2.88 —	4.34 (0.32)	4.93 (0.29)	5.44 (0.30)	6.18 (0.30)	6.80 (0.30)	7.7	5.0
Republic of Czechoslovakia	4.11	9.28 (0.87)	11.63 (1.04)	15.01 (1.93)	16.59 (1.9)	17.72 (2.12)	19.62 (2.61)	21.88 (2.06)	24.4 (2.66)	13.0

* Electric power plants located on the territory of the East German Democratic Republic; figures in parentheses refer to hydropower plants .

** In 1960 the People's Republic of China was 8th in the world, in terms of power generation.

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other countries of the people's democracies should also be mentioned. We rely heavily on Soviet engineering literature and consultation"[3].

Rumanian People's Republic. The Ten-Year Plan of Power Construction adopted in 1950 is being successfully implemented. Before 1950, Rumania had a total installed capacity of 600 Mw[4]. During the first three years of the Ten-Year Plan, the installed capacity rose by 50%. The largest scheme in the country is Bicaz Hydroelectric Station on the Bistrita River, built with Soviet aid in 1957. The storage lake on the Bistrita holds 1.2 billion m^3; the plant has a capacity of 210 Mw, and a yearly output of 450 million kwhr.

The storage reservoirs of these stations are an important source of water for the irrigation projects included in the Ten-Year Plan: irrigation of more than 1 million hectares — almost 45% of the country's arid lands — is envisaged. In 1960 Rumania had a total installed capacity of 1780 Mw (225 Mw hydropower) and produced 7.6 billion kwhr annually. From 1955 to 1960, installed capacity increased by 550 Mw including 125 Mw hydropower.

The construction of transmission lines was not neglected. In 1938 the only transmission line was the 110 km Dobroesti-Bucharest line. By 1959 the country had a total of 2100 km of H.V. lines.

Republic of Czechoslovakia. Hydropower engineering plays an important part in the economy of the country. Recent schemes include the 17-plant power cascade on the Vah River in Slovakia, and a number of large plants on the Vltava River, upstream from Prague. The main stage of the Vltava cascade is Orlik HEP, one of the largest in Central Europe[5]. Plans have been drawn up for the construction of 81 hydroelectric developments in the Vltava Basin. Storage lakes with a total volume of 1.6 billion m^3 will be formed; production of 1.3 billion kwhr/annum, i.e., 10% of the available hydropower resources is expected. These projects will improve navigating conditions on the Vltava between Ceske Budejovice and Prague.

Hungarian People's Republic. Power generation at the end and after the war was in a deplorable state. The basic aim of power construction in Hungary is, therefore, the construction of thermal power plants, which use cheap local fuel.

Hungary is not rich in waterpower resources and has only a few hydropower plants. In 1958, these plants had a total capacity of 9000 kw, producing 500 million kwhr annually [sic].

Since the war, Hungary has established the basis of a unified power system. By 1960 120 kv transmission lines had been extended to have a total line length of 2800 km. The first 220 kv line, Tisapolkonya-Szolnok, was recently commissioned.

The Hungarian power system is interconnected with the systems of Czechoslovakia, East Germany, Poland, and Yugoslavia, and receives 350 million kwhr yearly.

During the period of the 1961-1965 Five-Year Plan, output is to increase to 10.2 billion kwhr per annum. Jointly with Czechoslovakia, Hungary will erect a 120 Mw hydropower station on the Danube near Nagymoros. It is also intended to export electricity to the western regions of the USSR.

A result of the Hungarian power-construction program is that the per-capita consumption of electricity has reached 715 kwhr per year — five times the prewar (1938) level.

East German Democratic Republic. Brown coal is the basic source of energy in this country, and even this fuel is not available in sufficient

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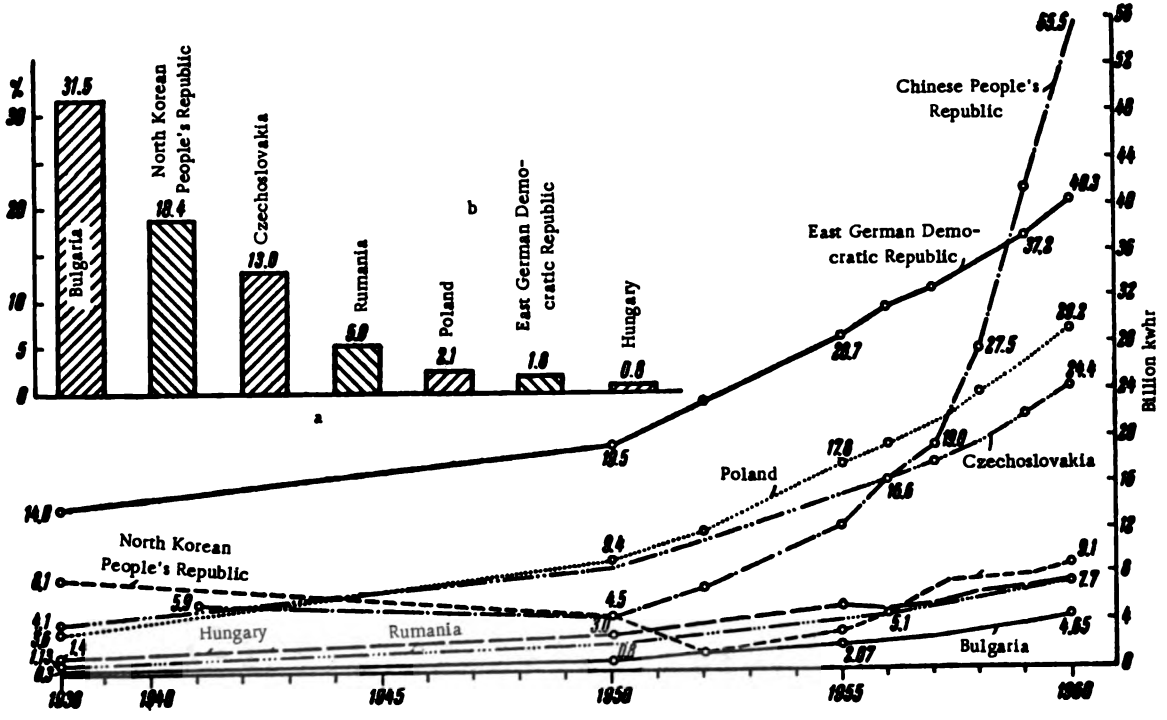

FIGURE 68. Power generation in the countries of the people's democracies

a — power production in the period 1938-1961; b — hydropower production

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quantities to satisfy the increasing demands for electricity. The water-power potential of East Germany amounts to only 2 billion kwhr/annum.

By the end of the war, the installed capacity of this part of Germany had dropped to 3 million kw, with a yearly production of 6.4 billion kwhr (in 1945).

According to data for 1960, the installed capacity rose to 7.25 million kw (including 200 Mw hydropower), and production to 40.3 billion kwhr/annum—98% of this from thermal power plants.

East Germany has a dense network of transmission lines: 8000 km of 110 kw lines, and more than 1000 km of 220 kv. The 1965 plan provides for the construction of another 500 km of 380 kv lines, 1100 km of 220 kv lines, and 2000 km of 110 kv lines. Much importance is attached to the construction of pumped-storage schemes, among them the large Hohenwarte No. 2 Station (320 Mw), and Amalienhöhe (300 Mw).

Polish People's Republic. The principle fuel used in the power stations of Poland at present is coal. In the prewar period, expansion of power supply was extremely low: in the decade 1928 to 1938, generation increased from 2.6 billion kwhr/annum to only 2.8 billion. The pattern changed radically after the establishment of a socialist regime in the country. In 14 years (1946-1960), electricity generated annually increased from 5.8 billion kwhr to 29.2 billion kwhr. By the end of 1960, the total installed capacity reached 7000 Mw, including 250 Mw of hydropower.

Poland's hydropower resources are estimated at 13 billion kwhr, of which less than 5% are utilized. During the period 1948-1959 installed hydropower increased by 74 Mw, which is 2.4% of the increase in installed thermal capacity. Most of the existing hydropower plants are small. Several hydropower plants are now under construction; the largest among them, on the Brda River near Koronowo, will have a capacity of 25 Mw.

In 1959 the total length of high-voltage lines reached 9000 km, including 960 km of 220 kv lines. In 1960 the length of 110 and 220 kv lines increased by 1450 km. Poland has power-line connections with Czechoslovakia, East Germany, and Hungary.

According to the national plan for 1959-1965, power generation is to increase from 24 billion kwhr/annum (1958) to 43.5-45 billion kwhr in 1965.

An instructive example of socialist power construction is the Turov power scheme. Brown-coal deposits of almost one billion tons exist at Turov. In 1957, East Germany gave the Polish Government a long-term (17 years) loan for the development of this area; technical information and equipment were also supplied. A 1200 Mw power station equipped with six large turbogenerators will be built. Output will be 8.6 billion kwhr per year; the annual fuel requirement will be 17 million tons. A series of storage reservoirs will supply water to the construction site of the plant; later the water will be used for operation. These reservoirs will be built by Czechoslovakian organizations.

Lenin's prophetic words at the VIII All-Russian Congress of the Soviets in 1920, on the influence of Soviet power construction on other countries, thus came true.

Lenin was very interested in the long-distance transmission of power both within the USSR and in other countries. In Lenin's opinion power construction was bound to become an important factor in international collaboration[6].

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The Ukraine was the first Soviet republic to translate Lenin's ideas on international power links into fact by establishing ties with its neighbors.

Hungary has extremely large bauxite deposits from which aluminum is extracted. Cheap electricity is needed for this process, and this power comes from the hydropower plants of the Western Ukraine. Czechoslovakia, in exchange for bauxite, supplies hydropower to Hungary. Poland will shortly start exporting electricity from the Silesian coal basin to Hungary. Steps are being taken to unite the power systems of the socialist countries to form a single power pool. A special committee has been created for this purpose with its seat in Prague[7].

Federal People's Republic of Yugoslavia[8]. Large-scale industrialization is associated with electrification. In this connection, aid received from the USSR and other socialist countries has been of great importance. By 1947 the prewar level of industrial production in Yugoslavia had been exceeded by 21%.

The basic trend in power development in Yugoslavia is the construction of hydroelectric plants, whose share in the total power supply of the country increased during the period 1946-1960 to 64%. The stress on hydropower development, an outcome of the lack of fossil fuel, determined the pattern of power generation during the last ten years. For the year 1961, a total installed capacity of 2500 Mw produced 9.92 billion kwhr yearly, of which 5.66 billion kwhr came from hydropower stations. (The figure for 1939 was 1.2 billion kwhr). The per-capita consumption rose to 560 kwhr/annum in 1961, against 72 kwhr in 1939.

During the period of Yugoslavia's second Five-Year Plan (1957-1961), the average rate of increase in installed capacity was 12.1%, and in generation (kwhr), 14.4%. This rate of expansion is one of the highest in Europe.

After the war, Yugoslavia constructed more than 60 power plants, including such large stations as Split HEP (425 Mw) and Dubrovnik HEP (416 Mw). However the high waterpower potential of Yugoslavia is not properly exploited: only 5% of a potential 66.5 billion kwhr/annum is produced.

Plans are being implemented to construct a giant cascade scheme on the Neretva River, with 14 plants having a total capacity of 930 Mw. The first of these plants at Yablanitsa is already operating. The capacity is 144 Mw.

Characteristic of the stations being put up in Yugoslavia are pier-built-in power plants and underground stations. These are the most suitable types for harnessing the numerous waterfalls of the country. Hydropower construction in Yugoslavia is influenced by the difficult geological and topographical conditions, particularly in the Karst regions, which occupy approximately one fifth of Yugoslavia. A technically interesting scheme is the harnessing of the Zeta River in the Karst region of Crna Gora [Montenegro]. This project is a complex of many engineering structures: 37 km of diversion channels and tunnels, an arch dam, two concrete dams, four earth dams, many water-intake structures and runoff-control works, hundreds of km of pipelines and various conduits. The average yearly output of the cascade when completed will be 1.1 billion kwhr. The main station of the scheme is the 216 Mw Perusie HEP (rated head 554 m). This station was commissioned in 1962.

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Of 16 underground stations in Yugoslavia, 11 are in the Karst regions. Karst is considered by Yugoslavian engineers to be reliable for structural foundations.

The building of underground plants was dictated mainly by geological conditions, but economic factors were also considered. Among the underground stations mention must be made of Viodol HEP (84 Mw, head 658 m), and Sen HEP (240 Mw).

A hydropower development near Iron Gates on the Danube is being built as a joint Yugoslavian-Rumanian venture. Soviet engineers were consulted at the planning stage. With an installed capacity of 1600 Mw (output 10.7 billion kwhr/annum) the development will utilize 9% of the total hydropower potential of the Balkan countries. The project is of particular significance for the power development of Rumania and Yugoslavia.

The USSR and other socialist countries currently grant technical and economic assistance to more than 20 underdeveloped countries in Asia, Africa, and South America.

Soviet engineers and specialists are working in Africa, India, Ceylon, and many other places. They are participating in the construction of more than 350 industrial projects.

An example of the assistance given to underdeveloped countries is the help granted to the U.A.R. An agreement between the USSR and the U.A.R. covering economic and technical assistance in the construction of the Aswan Dam was signed on 27 December, 1958. Under this agreement, the USSR has sent to the U.A.R. numerous specialists, equipment, and materials.

On 9 January, 1960, the official ceremony marking the beginning of work on the first stage of construction took place. The dam will be one of the largest in the world.

The Aswan Dam will have a height of 111 m and a crest length of 5 km. The storage reservoir will be 500 km long and will hold 130 billion m^3 of water (twice the volume of Kuibyshev Storage Lake). The hydropower station will have a capacity of 2100 Mw (close to that of Volga HEP im. Lenin). The output of the Aswan Plant (10 billion kwhr/year) will be much higher than the present figure for the whole country. Thanks to the dam, the U.A.R. will, by 1965, be able to reclaim 800,000 ha of land; 4 billion m^3 of water will be used for irrigating this land. By 1967, a further 4 billion m^3 will be used[9].

It is interesting to note that before the agreement between the USSR and the U.A.R., several companies in the western countries put forward proposals for the Aswan project. The German companies, Hochtiefbau (Essen), and Union Brueckenbau (Dortmund), and the British Company, Alexander Gibb, drew up various schemes, but all of them provided for an extremely complicated dam profile, which would have increased considerably the cost and construction time of the project.

Using their extensive experience in dam planning and construction, Soviet engineers worked out an optimum design, which involved minimum cost and construction time.

The French-language weekly "Image", published in Cairo, wrote appreciatively of the aid received from the USSR; without any secret stipulations, everything requested by the Egyptian government was sent, priority being given to the most urgently needed items.

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More than 100 Soviet plants and agencies participated in executing the orders received from the U.A.R. Soviet laboratories, and scientific research and design agencies developed special designs and materials for equipment to make it suitable for tropical conditions.

The hydroelectric giant on the Nile has become the symbol of Soviet friendship with the Eastern countries ("Izvestiya, 20 January, 1960).

A later agreement between the USSR and the U.A.R. covers aid in the construction of the Aswan Dam, up to the commissioning of the full power of 2100 Mw. The agreement also provides for the construction of 2800 km of high-voltage lines, and the building of an irrigation network for 840,000 ha of land.

Another example of Soviet assistance to other countries is the industrial aid granted to India in the construction of the large metalworks in Bhilai. The USSR also helps India in the construction of heavy plants for the manufacture of machinery and electrical equipment.

As far back as 1938, the late Pandit Nehru, when he was Chairman of the National Planning Committee, stressed the importance of planned economic development, and referred to the USSR as an example of a once backward country becoming one of the leading countries in the world[10].

The equipment, technical aid, and long-term credits, received from the USSR and the socialist countries all contribute to India's industrialization[11].

The metalworks in Bhilai receive electricity from Khikavud No. 1 HEP. In 1960 the Soviet organization LMZ designed and manufactured 25.4 Mw Kaplan turbines for Khikavud No. 2 HEP. Under an agreement, the Soviet Union gives India technical assistance in the construction of power plants in Neiveli, Korba, and Singrauli. The total power of these plants will be 850 Mw. The third Indian Five-Year Economic Plan (1961-1966) provides for the construction of a large dam and power plant (480 Mw) at Bhakra. On 21 February, 1961 a new assistance agreement was signed between the USSR and India in connection with this project.

The economic links between the USSR and Indonesia are developing satisfactorily. The USSR is providing assistance in the construction of a number of metalworks, of a 120 Mw hydropower plant on the Asakhan River with an associated transmission line, and an aluminum plant which will use cheap electricity from this plant.

Another country which receives Soviet aid is Cambodia. In a joint declaration issued by the USSR and Cambodia, the latter expressed its desire to receive Soviet aid in the construction of hydropower plants, and to be granted a long-term loan.

In 1959 the USSR signed an agreement with Nepal at Katmandu, the capital. This covered free assistance in the construction of a sugar plant, a cigarette factory, and a hydroelectric station.

Soviet help to Afghanistan is also proving very effective. Endless convoys of ships carrying machinery and equipment from the USSR and the socialist countries pass down the Amu-Darya River. The goods are unloaded in Afghanistan at the port of Kizyl-Kala, also built with Soviet aid.

It was Lenin who initiated Soviet-Afghanistan friendship. In a treaty of friendship concluded between the USSR and Afghanistan as far back as 1921, the intention that the friendly relations existing between the two countries should continue to develop was clearly expressed. The USSR also undertook to protect the independence of Afghanistan.

The implementing of Afghanistan's first Five-Year Plan was successfully completed in 1961. A development involving the construction of an

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irrigation system at Dzhelalabad, and hydroelectric stations at Pul-i-Khumri and Naglu is now being built. The 80 Mw so provided will double the generating capacity of Afghanistan. The irrigation project will serve 26,000 ha of land.

At the request of the Afghan government, Soviet specialists are helping to draw up another plan for the period 1961-1966.

Many African countries benefit from Soviet help. Thus, a joint Soviet-Guinean statement issued on Konakri on 1 March, 1960 refers to Soviet aid in the construction of a hydroelectric power plant on the Konkouré River. An estimated 3 billion kwhr will be generated annually. Electricity will be supplied to the aluminum plant at Fria. The 100 m high earthfill dam holds back a storage lake rivalling Lake Geneva in area. The volume of the earthfill is 25 million m^3.

The USSR will give Ghana technical assistance in the construction of a large power plant on the Black Volta River; a high-voltage transmission line is also to be erected[12].

An agreement was signed in 1960 between Cuba and the USSR on technical and economic assistance. The agreement covers assistance in the construction of power plants which will have a total power of 300 Mw. The assistance in the form of equipment and financial help will be provided during the period 1961-1965. National installed capacity will thus be raised 30%[13].

Many industrial and power plants are being erected with Soviet aid in Ceylon, Iraq, Ethiopia, etc.

Soviet help to Ceylon is instrumental in the carrying out of survey-exploration work, and the planning of irrigation systems and hydropower plants in the watersheds of the Malvatu-Oya, Kelani-Ganga, and Kala-Ganga rivers. Assistance is also being given in the reclamation of 5000 ha of bush land in Kanatalan and Khambantoga, which are to be used for growing sugar cane, and in the reconstruction of irrigation systems destroyed by heavy floods in 1957-1958.

More than 80 industrial enterprises are being erected in Iraq with Soviet help. Exploration work is being carried out on the Tigris and Euphrates. This will permit comprehensive development of these rivers for navigation and power generation.

Soviet specialists and consultants showed that the scheme drawn up by western companies for the construction of a dam on the Euphrates River near Yusef-Pasha is not economically sound. They have worked out their own scheme which calls for the dam to be erected at another site. This will allow the construction of a much larger power plant, and permit the irrigation of much more land. The Soviet scheme will require a smaller investment.

Soviet aid granted to underdeveloped countries is free of self-seeking motives. Soviet agencies are not interested in becoming partners in the enterprises set up with their help, they do not participate in the management of such enterprises, and do not receive any return. Assistance is given in the training of specialists and teams of technical personnel in the countries receiving aid.

Soviet loans bear only 2.5% interest. The loans are repayable over a 12 year period. Repayment may be made in the form of locally produced goods. This can be helpful to the program of economic development of the country concerned.

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Soviet practice is quite different from that of capitalist companies. With the equipment and the materials, these companies normally send their own specialists. They hire local labor in the country. After setting up an enterprise, the foreign company continues to participate in its management, and receives a large return on the investment.

The successful implementation of the Seven-Year Plan in the USSR opens new vistas for widening technical and economic collaboration with the underdeveloped countries.

Of the Soviet Seven-Year Plan, an Indian newspaper "Svatkminata" has written that its successful implementation will benefit both the socialist countries and the countries of Asia, which have recently become independent states.

At an early point in the existence of the Soviet regime, Lenin expressed his strong belief in Russia's future as a powerful country and an example to the workers of the entire world[14]. It is now clear how right Lenin was.

NOTES

[1]Lenin, V.I. Sochineniya (Works), Vol. 31, p. 422.

[2]Nesteruk, F. Gidroelektrostantsii Bolgarii (The Hydropower Stations of Bulgaria).— Gidrotekhnicheskoe stroitel'stvo No. 3, p. 21. 1945.

[3]Nikolov, S. Gidroenergeticheskoe stroitel'stvo v Narodnoi Respublike Bolgarii (Hydropower Construction in the Bulgarian People's Republic).— Gidrotekhnicheskoe stroitel'stvo, No. 5, p. 55. 1961.

[4]Nesteruk, F. Gidroelektrostantsii Rumynii (Hydropower Plants of Rumania).— Gidrotekhnicheskoe stroitel'stvo, No. 7. 1945.

[5]Orlik HEP has four Kaplan turbine units each rated at 90 Mw; the runner diameter is 4.6 m, the number of runner blades 10, the discharge through the turbine 150 m^3/sec, the rotational speed 187 rpm, the load on the thrust bearing 1400 tons, and the head 71.5 m.

[6]Lenin, V.I. Sochineniya (Works), Vol. 33. p. 112.

[7]Ekonomicheskaya Gazeta, No. 7. p. 40. 1963.

[8]Borba, 6 May, 1962; Elektroprivreda Nos. 2 and 10. 1961; Statisticki godisnik FNRI, Nos. 4 and 5. 1962. Jevdjevic, V. Vodne Snage Jugoslavije (Yugoslavia's Water Resources). Boegrad. 1956.

[9]Zaki Khassan. Vysotnaya Asuanskaya plotina Sadd el'-Aali (The Sadd-El-Aali High Dam at Aswan).— Gidrotekhnicheskoe stroitel'stvo, No. 3. 1959.

[10]"National Planning Committee. Engineering Industries connected with Scientific Instruments", p. 28, Chairman Pandit Jawaharlal Nehru. Bombay. March 1948.

[11]For more details on the development of hydropower in India see the study by the present author: Vodnye resursy Indii i ikh ispol'zovanie (India's Hydropower Resources and their Utilization).— In Sbornik "Iz istorii nauki i tekhniki v stranakh Vostoka", No. 1, Moskva. 1960.

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[12]Nesteruk, F. Rechnye sistemy Respubliki Gana (The River Systems of Ghana).— Rechnoi transport, No. 12. 1962.

[13]Nesteruk, F. Vodnye resursy svobodnoi Kuby (The Water Resources of Free Cuba).— Rechnoi transport, No. 8. 1962.

[14]Lenin, V.I. Sochineniya (Works), Vol. 26, p. 407.

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Chapter VIII

PROSPECTS FOR THE DEVELOPMENT OF HYDROPOWER IN THE USSR

"Great attention will be paid to the preservation and rational utilization of forests, water resources, and other natural assets."

From the Program of the Communist Party of the Soviet Union

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The policy of the Soviet Communist Party to promote large-scale construction of hydropower plants becomes more understandable, when it is remembered that the hydropower potential of the USSR is comparable with that of the U.S.A., Western Europe, and Canada together. The 4500 large and medium-sized rivers of the USSR could be harnessed to generate about 3000 billion kwhr per year (378 million kw).

When the power-construction program of the Seven-Year Plan is completed, the utilization of the estimated power available will only be 5-6%.

The new program of the CPSU adopted in October, 1960[1], contains an outline of the development planned for the power-supply industry for the next 20 years. By 1970 generation should reach 900-1000 billion kwhr/year, and by 1980 it should reach 2700-3000 billion[2]. This means that generating capacity will have to be installed at an increased rate. By 1970 a further 190-220 million kw will have to be commissioned, and by 1980 — 540-600 million. This cannot be done except by building large power plants. At present, the yearly increment in installed capacity is 7 million kw; by the end of the Seven-Year Plan period, it will be 12-13 million kw. By the end of the subsequent decade it should reach 20-25 million kw, and, after a further decade, 45-50 million kw yearly. Tentative calculations show that for an installed capacity of 600 million kw, it is necessary to build 200 large thermal power plants, 260 combined thermal (district heating) and power plants, 180 large hydropower plants, and hundreds of thousands of kilometers of transmission lines.

Such a rate of expansion requires radical changes in power-construction policy, particularly with regard to hydropower.

The main stress must be laid on the production of designs for large hydropower developments, which make use of local materials, and require minimum quantities of metals and lowest capital expenditure.

For the next 20 years the program covers the large-scale harnessing of lowland rivers, and the regulation of those rivers on which power plants already exist (Volga, Kama, Dnieper, etc.).

A capacity of 2900 Mw will be installed on the Volga at Cheboksary HEP and Lower Volga HEP; four stations on the Upper Volga will together have a capacity of 360 Mw. On completion, the Volga cascade scheme will have a total installed capacity of 9120 Mw, with an annual average output of 43 billion kwhr. The cascade scheme will make the Volga navigable over its whole length and allow the irrigation of huge tracts of land.

The Kama cascade scheme is to consist of the 1400 Mw Lower Kama and the 1504 Mw Upper Kama plants. The output of the scheme is expected to be 8.2 billion kwhr per year.

It is planned to divert some of the northern rivers into the Volga (through the Kama River). This will increase the water storage of the Volga and raise its power-generation potential by 10 billion kwhr per annum. Two

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of these northern rivers, the Vychegda and the Pechora, have a total storage of 40 billion m^3. The realization of this plan will improve the runoff control of these rivers and also help to stabilize the level of the Caspian Sea [at present continuously dropping]. Better irrigation will be possible of the arid regions in the Volga area and in the Volga-Akhtyuba flood plain. Coal found plentifully in the Pechora Basin will be carried on the new waterway to the Ural and Volga industrial areas. The total annual output of the Volga-Kama scheme will exceed 61 billion kwhr.

By 1970, the total power of the Dnieper cascade will be 3.5 million kw (annual production up to 10 billion kwhr). This cascade will be completed after Kiev and Kanievo HEPs are built.

In addition to the existing 40 Mw Dubossary station, six more hydroelectric stations are necessary for the full exploitation of the Dnieper. These stations are Unizhskaya, Mogilev-Podol'sk, Zhvanginskaya, Yampol', and Nizhnevskaya, in the Ukraine, and Kamenkovskaya in Moldavia. The capacity installed at these plants will be 2 million kw.

The plans for the development of the Caucasus area provide for the harnessing of the large waterpower resources. Thus, in Georgia, top priority is being given to the construction of the Inguri cascade of three plants: the Inguri, Khudoni, and Tobari stations, total capacity 1.4 million kw. These plants, together with those on the Rion, Kura, and Parovan rivers, and in conjunction with some thermal plants, will ensure reliable power supply to Georgia.

The four existing power plants on the Kura River will be supplemented by others — the Akstafinskaya and Tauzskaya plants, three diversion-type plants on the irrigation canals of the Azerbaidzhan SSR, and Agara HEP in Georgia. On completion, the Kura cascade will have a power of 1 million kw. It is bound to play an important part in the supply to the interconnected Caucasus power systems.

The next step after the completion of the Sevan-Razdan cascade in Armenia, will be the construction of a new cascade on the Vorotan River. The first stage of the cascade will be the 100 Mw Tatev HEP.

In Central Siberia the large rivers, Angara, Yenisei, Ob, Tomi, and Lena have a total potential of 250 billion kwhr per annum. In this area hydropower development is progressing extremely rapidly. In the not too distant future, other Siberian rivers, such as the Aldan, Vitim, Selengara, and Tom will also be harnessed.

When Bratsk HEP, the very large station on the Angara, was completed, construction started on Ust'-Ilim HEP, which will be of similar size. Another project will be built on the Lower Angara.

Rapid progress is being made on the world's largest hydroelectric plant, the 5000 Mw Krasnoyarsk station (Figure 53). Commissioning is scheduled for 1967. The dam for this project on the Yenisei was completed during the spring of 1963. The dam is causing a very large storage reservoir of 73 billion m^3 to form. Filling will be completed by August 1966.

Plans have been drawn up for the construction of a still larger plant on the Yenisei, not far from the confluence of the Angara and Yenisei rivers. The capacity of this plant will be 6 million kw. Survey and exploration work have started in preparation for the construction of three more large hydropower plants [on the Yenisei], the largest of these will be the Sayanskaya HEP (over 5 million kw).

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Novosibirsk HEP is the first stage of the cascade scheme on the Ob River to be commissioned. Kamenskaya HEP is to be built upstream from the Novosibirsk Plant. The storage lake of the Kamenskaya HEP will boost the power output of Novosibirsk. Plans exist for the construction of Lower Ob HEP at a point on the river near its inflow into the Gulf of Ob. This station will generate 35 billion kwhr annually.

Due attention is being given to the arid lands of Central Kazakhstan. Hundreds of industrial projects have been built here in recent years; the largest metal working complex in the USSR, Karaganda Integrated Works, will be completed in this area by the end of the Seven-Year Plan period. These plants require very large quantities of water. This will be taken care of by the construction of the Irtysh-Karaganda Canal, the streamflow of which will be comparable with that of the Oka River. The start of this new canal, which is aptly called by the local inhabitants "Tlegen-Sul" [Desired Water], is the village of Ermak near the town of Pavlodar. It passes through the Ekibastuz coal region, the end of the canal being at Karaganda. The total difference in level is 500 m. Pumping stations will be erected along the route of the canal. These will constitute a load almost equivalent to the total national load of Tsarist Russia in 1913.

Similar water-management projects are being designed for Donbass and the southern part of the Ukraine, where the water-shortage problem is chronic.

The fact that the Lena River area is in the severe-climate area of the permafrost region makes hydropower construction much more difficult. The first projects in this area are being built on the Mamakan and Vilyui rivers.

The Amur, one of the greatest rivers in the USSR, is 4367 km long; it has the extremely high streamflow of 346 km^3 per year, and a large catchment area — 2,050,000 km^2. The hydropower potential of the river is estimated to be 100 billion kwhr per year. Part (46 %) of the catchment area of the Amur is in China. Extensive summer floods occur and these make it necessary to build large flood-control works. This river will be harnessed for the benefit of the area through which it runs.

A Sino-Soviet commission established that, for effective flood control, large regulating control storage lakes are necessary. The first of these should be located on the upper reaches of the river and on its tributaries, the Shilka, Argun', and Bureya (Figure 69). These storage lakes will also make possible the harnessing of the Amur for power generation[3].

The catastrophic floods which frequently occur in the Upper Amur Region are due to the Amur tributaries, the Shilka and Argun', which discharge 27 km^3 of water annually into the Amur. The storage reservoir of Amazarskaya HEP, which will be built not far from the point of confluence of the Shilka and the Argun, will give complete runoff regulation of these two rivers. It is intended that Kuznetsovskaya HEP, which is to be erected near Cherpel'skii Krivun, will have a storage reservoir of 166 billion m^3. This will give runoff control for the upper reaches of the Amur. Several plants are to be built on the Argun' and on the Onon, one of the sources of the Shilka.

A large development for regulating flood runoff and for power generation will be built in the region of the Upper Zeya River[4]. Similar developments are planned for two tributaries of the Zeya, the Selemdzha and the Bureya.

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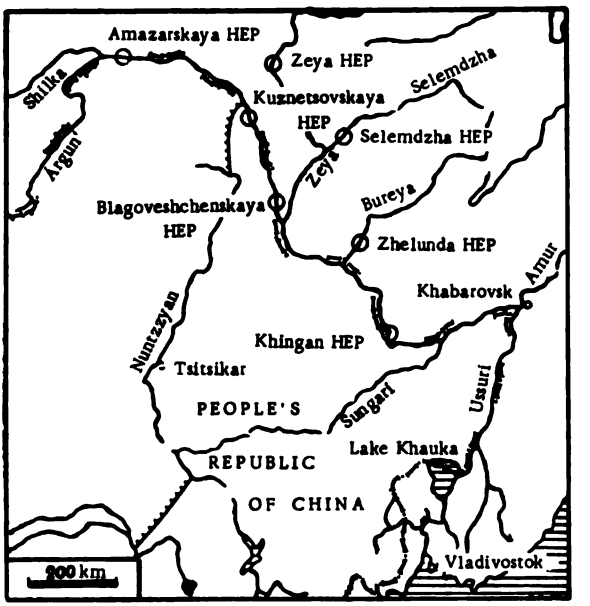

FIGURE 69. Navigation and power developments in the Amur River basin.

The largest hydropower development in the Amur Area will be built on the steep banks of Khingon Canyon.

Two hydropower plants, Komsomol'sk and Lower Amur, will be built on the Lower Amur, downstream from the confluence of the right-hand tributary, the Ussuri.

The Amur River basin has a hydropower potential of 45 million kw. About 70 plants, capable of providing 15-18 million kw and a yearly output of 90 billion kwhr, will be built here. This bodes well for the industrial development of the Amur Area.

Water-borne transport is bound to play an important part in the development of the region. The construction of hydropower projects with navigation locks creates a reliable waterway, but the shallow water near the mouth of the Amur is an obstacle to navigation. About 250 km from its mouth, the Amur comes close to Lake Kizi. A canal which passes through this lake links the Amur with the Gulf of Tatary. This canal will give ocean-going ships access to the Amur. When the lower reaches of the Amur are regulated, the towns of Komsomol'sk and Khabarovsk will become sea ports. Plans have been drawn up for a canal, the route of which will be Ussuri River — Lake Khanka — Suifun River. This canal will be used for navigation, soil reclamation, and water supply. It is planned to construct another "artificial" outlet for the Amur to the Yellow Sea. To this end, the Sungari River, a tributary of the Amur, will be connected to the Liao Ho River, which discharges into the Po Hai [Gulf of Chinli], by a 300 km canal.

After completion of this project, it will be possible to establish a continuous waterway on the Amur, connected to three seas — the Sea of Okhotsk, the Sea of Japan, and the Yellow Sea.

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The development plans for power supply in Central Asia are based on the water resources, the potential of which is estimated at 225 billion kwhr/annum. (Only 2% of these resources have so far been utilized).

The plans for the completion of the Chirchik River cascade have been completed. This scheme involves the construction of Charvakskaya HEP (480 Mw) on the Upper Chirchik, and Central Chirchik HEP.

After the commissioning of Chardari HEP (100 Mw) on the Syr Darya, construction work started on a comprehensive scheme to harness the Vakhsh River, a tributary of the Amu-Darya, in Tadzhikistan. The 30 Mw Perepadnaya HEP on an irrigation canal in this area is now operating at rated capacity. Golovnaya HEP (210 Mw) on the Vakhsh has also been commissioned, and construction has started of Nurek HEP (2700 Mw), the largest station of the Vakhsh cascade. Three other hydropower plants are planned for the Vakhsh: the Rogunskaya, Sychuranskaya, and Shurobskaya plants, which will have a total capacity of 2500 Mw. It is intended to erect the large Tuya-Myrun development on the Amu Darya.

Preliminary work has started on the construction of the 360 km third stage of the Karakum Canal. This stage starts at the town of Mara, crosses the Tedzhen River, and reaches the town of Ashkhabad. After completion of this stage, the total length of the canal will be 820 km. This will make it the largest irrigation system in the world.

A few words on the prospects for tidal-power plants. The low cost of power generation at such plants, particularly when they are favorably situated, makes them a promising line of research. Much research has been done in the USSR in this field. Lumbovskaya Tidal-Power Plant in the northwest of the USSR, with a planned capacity of 320 Mw, is considered to be the best of the schemes investigated. Plans have also been worked out for the construction of tidal stations in the Gulf of Kuloi and the Gulf of Mezen[5].

During the current Seven-Year-Plan period the power systems of the USSR will be interconnected to form large zonal power pools. The European-USSR Power System will be formed and subsequently interconnected with the systems in Siberia, Central Asia, Kazakhstan, and the Caucasus. The unified power system so created will include most of the power plants of the inhabited area of the USSR (Figure 70).

In the USSR at present, the most economic voltage for transmission over distances of 1000-2000 km is 400 kv.

Transmission lines from the power plants of Siberia and the center of the country will have to carry 30-50 billion kwhr annually over distances of 2000-2500 km. Calculations have shown that the most suitable system for these lines will be d-c transmission. Thus, the capital cost of a d-c line from Lower Ob HEP to the Ural area will be less than half of that of a corresponding a-c line. Losses on the d-c line will be 8.9% less and the cost of transmission will be reduced by 39%.

Existing plans provide for the d-c transmission of the 30 billion kwhr/year produced by Lower Ob HEP to the Ural Area and neighboring regions in 1975. The voltage level will be ±700 kv and the length of the transmission line 1800 km.

Both a-c and d-c intersystem transmission lines are bound to play an important part in the development of power supply. It is intended to erect

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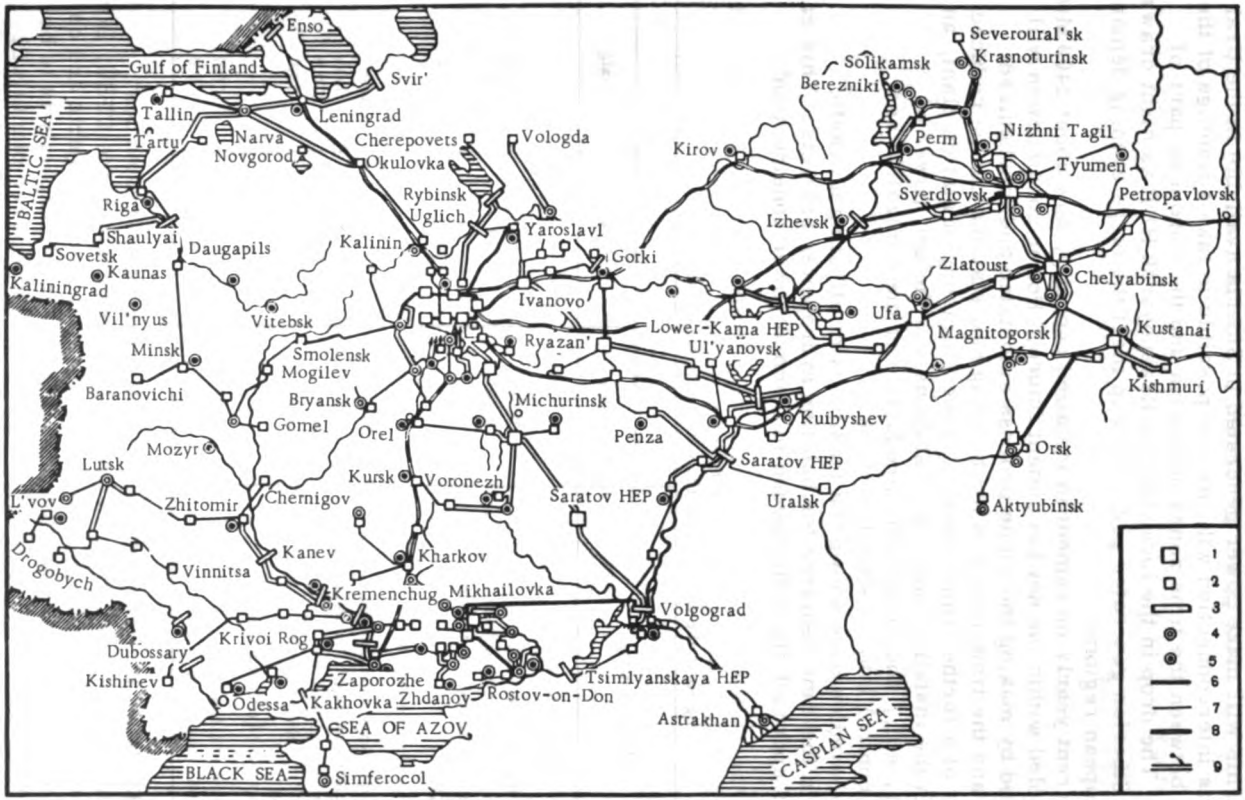

FIGURE 70. The European-USSR Power System (development to 1965)

1 — 400 kv or 500 kv substation; 2 — 220 kv substation; 3 — hydropower plant; 4 — thermal power plant; 5 — power-supply region with thermal-station capacity of 50 Mw or more; 6 — 400 kv or 500 kv transmission line; 7 — ditto 30-220 kv; 8 — electrified railroad; 9 — transmission line scheduled for conversion to 400 kv

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not less than 40,000 km of 500 kv a-c lines and 12,000 km of high-voltage d-c lines.

The powerful Yenisei-Ural intersystem tie will connect two very large power pools — the European-USSR Power System and the Central Siberian System. This will make power generated in Siberia available in the Ural Area. This interconnection will make it possible to take advantage of the difference between the time zones of Siberia and the European part of the USSR. The drop in the local load on Krasnoyarsk HEP as night draws on will allow Siberian generated power to help meet the large evening demands in the European regions.

The current yearly increment in installed capacity, now about 2400 Mw, will be tripled within the not too distant future. Power construction will be improved by making the whole process automated and mechanized.

Costs, and the time required for building new stations can be reduced as a result of a further improvement in the efficiency of station plant, an increase in the installed capacity of stations and the unit power of generators, etc., and maximum introduction of mechanization and automatic control into construction work.

Detailed studies have shown the feasibility of effecting a drastic reduction in the time required for building hydropower projects. This can be made to approach the time needed in thermal power construction[6].

TABLE 33

Progress in the utilization of the water-resources of the USSR

Main branches	Year		
	1913	1940	1960
Hydropower			
Installed capacity, Mw	0.016	1.58	14.8
Electricity produced billion kwhr	0.04	5.1	51.0
Percentage of hydropower in the total power supply	1.7	10.5	17.4
Navigation			
Length of waterways, thousand km	64.6	107.3	140
Length of canals included, thousand km	3.1	4.6	12.1
Freight carried, million tons	35.1	72.9	210.3
billion ton-km	28.9	35.9	99.6
Land reclamation			
Irrigated area, million ha	3.96	6.1	175.0
Drained area, million ha	2.8	6.0	9.0

Table 33 shows the progress made in utilizing water-resources[7].

The new Twenty-Year Plan, in line with the program of the CPSU, lays much stress on the construction of highly efficient power projects and on runoff control and river regulation. Storage-reservoir capacity is to be increased by a factor of 5.5, power output from hydropower plants will increase by as much as 12 times, the area of irrigated land will go up by a factor of 2.2, and 3.6 times more freight will be carried on waterways.

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NOTES

[1] Materialy XXII s"ezda Kommunisticheskoi partii Sovetskogo Soyuza (Transactions of the XXII Congress of the CPSU).— Gospolitizdat. 1962.

[2] The unprecedented scale of the new power-construction program can be seen from the fact that by 1980, Soviet output will be close to the level of world output in 1960, i.e., 2500 billion kwhr/year.

[3] Nesteruk, F. Razvitie gidroenergeticheskogo stroitel'stva v Kitaiskoi Narodnoi Respublike (Power Construction in the People's Republic of China). —In: Sbornik "Iz istorii nauki i tekhniki v stranakh Vostoka", No. 2, p. 41, Moskva. 1961.

[4] The urgency of developing the water resources of the Amur has led to top priority being given to the Zeya development. Other projects on the Amur will also be erected during the period of the current Seven-Year Plan.

[5] Bernshtein, L. Opytnaya prilivnaya elektrostantsiya (A Pilot Tidal-Power Plant).— Gidrotekhnicheskoe stroitel'stvo, No. 3. 1962.

[6] Khrushchev, N.S. Rech'na mitinge stroitelei Volzhskoi gidroelektrostantsii imeni V.I. Lenina (Address to the Constructors of Volga HEP im. Lenin), p. 13, Moskva. 1958.

[7] Zvonkov, V. Vodnye resursy — narodnoe dostoyanie (Water Resources — in the Hands of the People). Moskva. 1962.

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Conclusion

HISTORICAL SURVEY OF THE DEVELOPMENT OF HYDROPOWER CONSTRUCTION IN THE USSR

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The Soviet people have achieved remarkable success in creating a strong power-supply industry which supports the growth of the economy. The national installed capacity in 1960 — 65.26 million kw (including 14.8 million kw of hydropower) — was 60 times greater than that of Tsarist Russia (Figure 71). During the Soviet regime, generated output has increased by a factor of 150; in 1960 it reached 292.3 billion kwhr, including 50.9 billion kwhr from hydropower stations (Figure 72). During 1961 another 1.6 million kw of generating capacity were installed, bringing the total to 16.4 million — more than a thousand times above the level of Tsarist Russia.

Power output in the western countries has also increased, but at a much lower rate (Figure 71).

Particularly impressive is the success in electrification: the level of electrification is now equivalent to overfulfillment of the figures of the GOELRO Plan by a factor of 35. The USSR is the first country in Europe in terms of electricity production, and the second in the world (Figure 73).

Still more impressive is the success obtained in hydropower construction. During the Soviet regime, the output of these plants has increased by a factor of 1700 and their share in the total power supply has reached 20%.

Soviet hydro plants now produce in about one hour and a half more electricity than they produced during the whole of the year 1920! In only ten days, hydropower plants now produce the same output as all the power stations of Tsarist Russia produced in a year. Figures 71 and 72 are eloquent illustrations of the tremendous growth in Soviet power construction.

The GOELRO Plan of electrification was implemented in a very short time, and during the period from 1920-1930 the national installed capacity increased by a factor of 2.3 (in hydroplants by a factor of 7). At the same time, output increased by a factor of 16.

The level of hydropower generation was, however, very low. The installed capacity of hydroelectric stations in 1930 did not exceed 128 Mw, and output was 555 million kwhr/year. The share of hydropower in the total power supply was only 6.6%. During the thirties construction of hydropower plants appreciably improved the situation.

By 1935, new installed capacity was equivalent to 12.48 times the GOELRO Plan figures; power production rose from 520 million kwhr in 1921 to 26.3 billion in 1935 (GOELRO Plan figure — 8.8 billion). In 1935 the total installed capacity reached 896 Mw, and the total length of transmission lines attained 1200 km (109 km in 1913). The highest transmission voltage in Tsarist Russia was 35 kv. In 1935, many lines were operated at 220 kv, and the first power systems were formed.

In Tsarist Russia the average plant capacity factor was 21-22%, while maximum utilization did not exceed 1920 hours per year. By 1934 the plant capacity factor had gone up to 45% for regional power plants, and the average number of hours of utilization had increased to 4000. In Western

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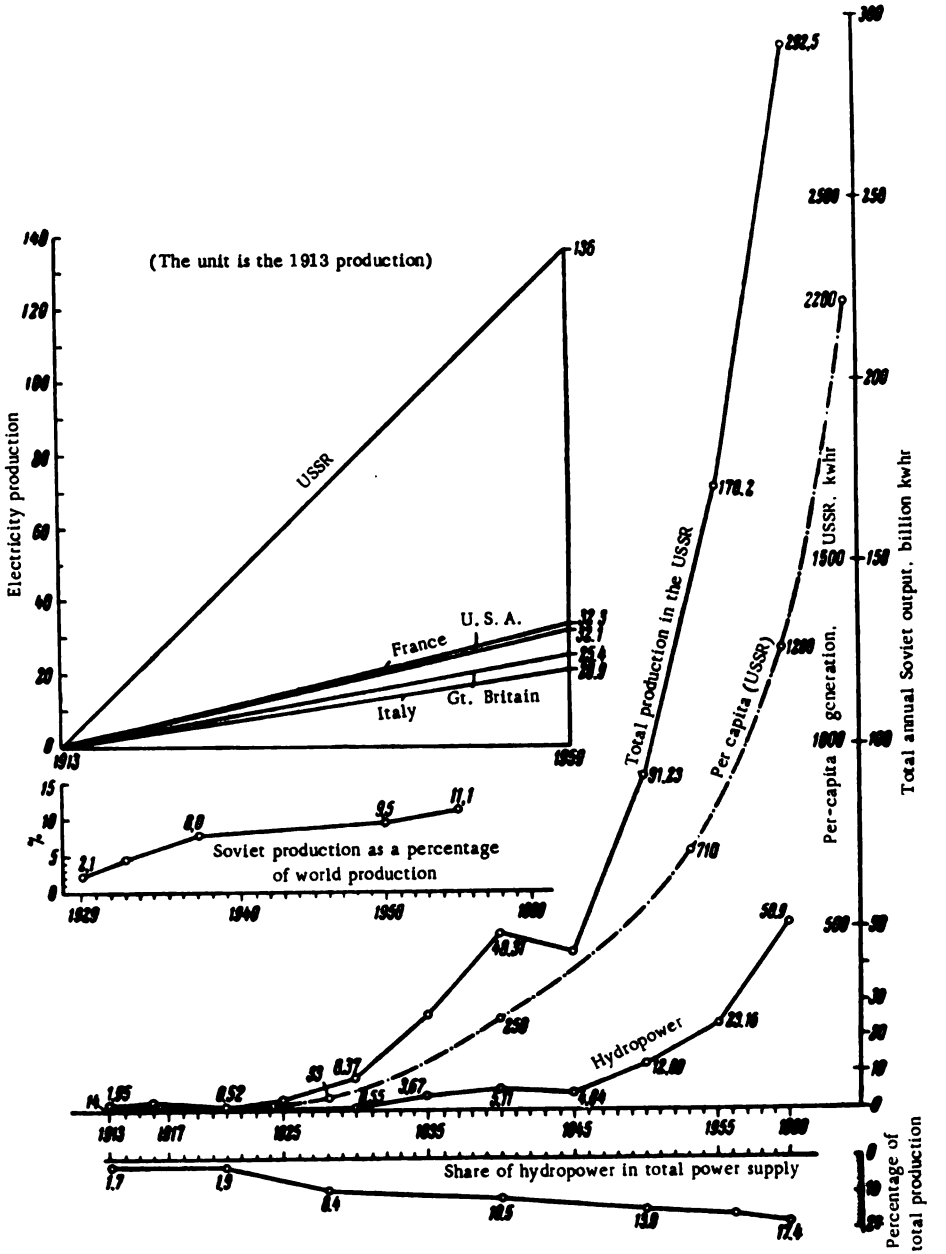

FIGURE 71. Growth of power production in the USSR and some western countries

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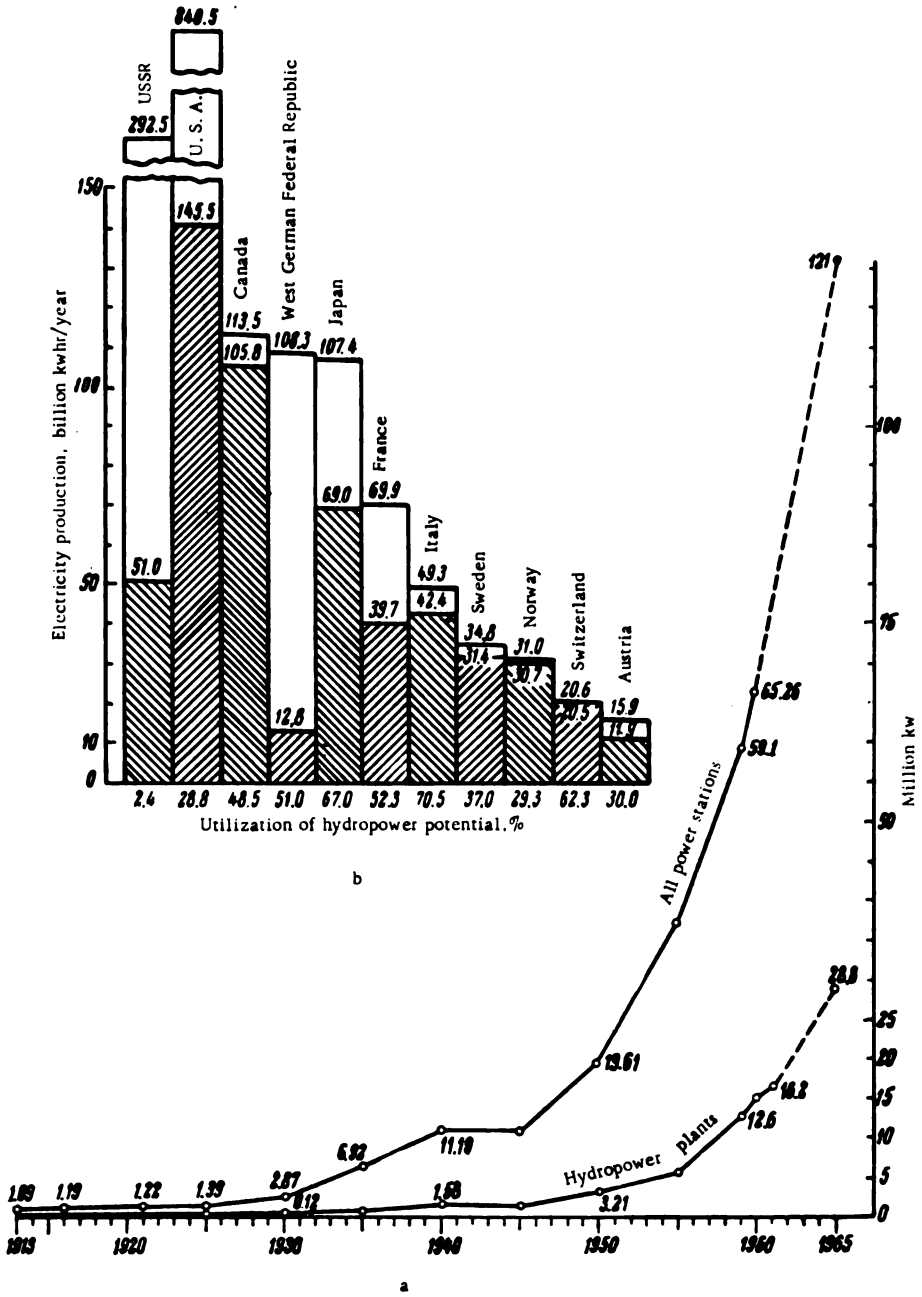

FIGURE 72. Growth of installed capacity in the USSR, and utilization of hydropower potential.

a — growth of installed capacity in the USSR; b — utilization of hydropower potential in some foreign countries. Cross-hatched area is the share of hydropower in the total power supply.

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countries in the same year, the number of hours was much smaller: 2527 in the U.S.A., 2167 in Germany, and 2034 in Gt. Britain.

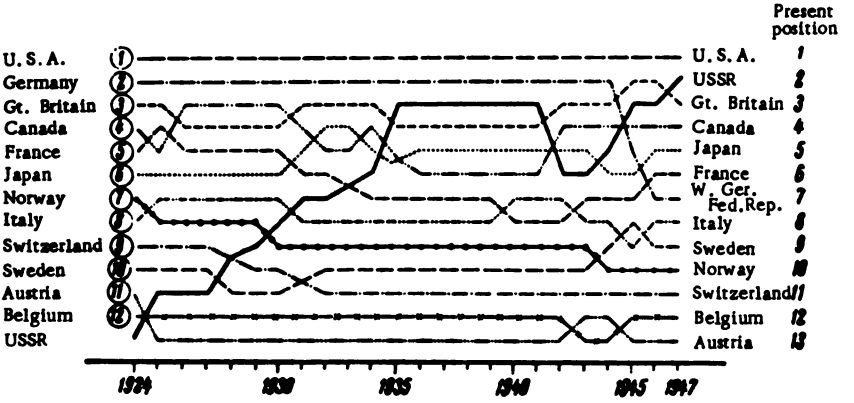

FIGURE 73. Leading electricity-producing countries, arranged according to output figures on the left — order in 1924; figures on the right — order in 1947.

The rate of developing the power-supply industry steadily increased. Only ten years after the publication of the GOELRO Plan, the USSR overtook six other countries in terms of power production: by 1935 the Soviet Union had climbed to third place after the U.S.A. and Germany (Figure 73).

In 1940 output in the USSR reached 48.3 billion kwhr/year (1.95 billion in 1913).

The USSR shows up well when the yearly increment in installed capacity is compared with the low rates of other countries. Thus some mean yearly increments in output during the period 1937-1939 were: Gt. Britain 2 billion kwhr; Japan 1.67 billion; in France production actually dropped during this period. In the USSR during the three years 1938 to 1940, output increased to 121.1 billion kwhr with a yearly increment of more than 4 billion kwhr. Such rates of development left no doubt that the USSR would shortly reach second place in the world, in terms of power production.

During World War II, the Soviet power-supply industry suffered heavy losses: more than 6 million kw of installed capacity were destroyed or heavily damaged. These heavy losses were made good. During the war (1942-1944) more than 3.4 million kw of new capacity were commissioned in the Eastern regions (Ural, Siberia, Kazakhstan, and Soviet Central Asia). By the end of 1945 (i.e., shortly after the war), six large hydroelectric stations, with a total capacity of 260 Mw, had been reconstructed. Stress was laid on increasing the efficiency of machines, and raising the unit power of the items of equipment installed.

The special efforts made in reconstruction work enabled the Soviet Union to reach second place in power generation (after the U.S.A.) by 1947. Since then, the gap between these two countries has steadily narrowed (see Figure 73).

The annual increment in installed capacity is ever increasing. During the period 1936 to 1940, the yearly increment was 733 Mw; during the

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reconstruction period (1945-1949) the yearly increment was 1205 Mw; and during the subsequent five-year period (1951-1955), the annual addition was 3024 Mw.

In this tremendous growth of installed capacity, hydropower construction plays a significant role (Table 34).

TABLE 34

Development of hydropower in the USSR

Years	Installed capacity, Mw	Output, million kwhr/year	Percentage hydropower in the power supply
1913	16	35	1.7
1921	18	10	1.9
1928	121	430	8.6
1940	1,587	5,113	10.5
1950	3,218	12,691	13.9
1955	5,996	23,165	13.6
1956	8,498	28,984	15.1
1959	12,710	47,630	17.9
1960	14,781	50,913	17.4
1965 (Target figures)	28,800	100,000	18.0

The period of the fifth Five-Year Plan (1951-1955) was marked by greater progress in power construction. Thus, the yearly increment in installed capacity was more than the total capacity covered by the GOELRO Plan. In 1951 alone, installed capacity increased by 3 million kw. For the period 1951-1955, average annual increments in the installed capacity in a number of countries were (percentages): USSR 12; West German Federal Republic 9.2; U.S.A. 7.1; Italy 6.7; France 8.4; Gt. Britain 7.4; Japan 7.8.

The total installed capacity (all plants) during the period of this Five-Year Plan almost doubled, while that of hydroelectric stations increased by a factor of three. Output increased by 87%, reaching 170 billion kwhr/year (this includes 23 billion kwhr hydropower).

In the following four years (1955-1958), installed capacity increased by more than 20 million kw (5.7 million kw hydropower).

By 1958, the last year before the period of the Seven-Year Plan, generated output had increased by a factor of 123, compared to the figures for 1913.

The further development of power supply in all districts of the country is of the utmost importance for industrial progress. Thus five Republics in Soviet Central Asia, Uzbekistan, Turkmenistan, Tadzhikistan, Kirgizia, and Kazakhstan, with a total population of 23 million, possess about 20% of the hydropower potential of the USSR; in 1957 the electricity generated in these five republics was greater than the total generated in Turkey, Iran, Pakistan, Afghanistan, and Thailand together. The total population of these countries is more than 156 million.

The impressive achievements of Soviet power construction are so evident that they cannot be denied even by those not friendly toward the USSR. However, if forced to recognize Soviet successes, they try to

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play down their importance. Thus, the periodical "Economic Geography", published an article, "Power Engineering in the USSR", by Professor Tiel of Munich. The article contains much information on Soviet achievements and draws heavily on Soviet sources. Unable to deny Soviet successes, the author tries to minimize their significance. He writes that it is not practical to construct hydroelectric power plants in the East-European territory of the USSR because of extremely low land relief. He claims that the increase in power construction in this area is very low, and that any development that does take place will have a negligible effect for a long time.

The facts deny these conclusions. By 1950, Soviet power production had increased by a factor of 2.5 compared with 1940, and this rise was mainly due to increase of output in the East-European territory of the USSR.

From year to year the rate of increase of generating capacity goes up. In the first year of the new Seven-Year Plan (1959) 5.6 million kw of new capacity were installed. In the same year production reached 265 billion kwhr, thus exceeding the combined production of electricity in Gt. Britain, France, Italy, and Sweden.

During the period 1931-1959, power production increased in the USSR by a factor of 136, in France by 32.3, in the U.S.A. by 32.1, in Gt. Britain by 24, and in Italy by 20.9.

For the three years 1957-1959 the yearly increment of production was 10.9% in the USSR, and 4.9% in the U.S.A.

During 1960 alone, new capacity commissioned was equivalent to almost four times the total new capacity called for by the GOELRO Plan for a 10-15 year period. The capacity of Volga HEP im. Lenin (2.3 million kw) is more than that laid down in the GOELRO Plan for installation in 10-15 years.

At present, newly installed capacity, calculated as a daily average, is 16 Mw (including 5-6 Mw of hydropower). This is striking disproof of the remarks of the enemies of the USSR[3].

The implementation of the provisions of the Seven-Year Plan regarding power construction constitutes a decisive stage in the fulfillment of Lenin's plan of comprehensive electrification of the Soviet Union. It is intended to double the installed capacity and the power output during this period. This will require an annual increment in capacity of up to 15 million kw. Even these figures will have to be increased for subsequent Seven-Year Plans.

The successful fulfillment of the target figures in the early years of the current Seven-Year Plan made it possible to revise the later target figures for the installation of generating capacity, increasing them to 68 million kw, and the output to 550 billion kwhr (in 1965). It was originally planned to increase the installed capacity of hydropower plants during the period 1959-1965 by 10-11 million kw. Progress was such that the suggestion was made to put up this figure to 18 million kw; 14 million kw would be installed during the period 1961-1965, of which 1.6 million would be put in during 1961.

The increase in production planned for 1965 is greater than the 1954 annual production of all European countries. The U.S.A. required 13 years (1941-1954) to increase production from 208 to 546 billion kwhr/year. A similar rise in production is scheduled for only eight years (1957-1965) in the USSR.

Comprehensive electrification makes extensive construction of high-voltage overhead lines necessary: more than 200,000 km of such lines are to be built during the current Seven-Year Plan period. In terms of transmission voltage, Soviet a-c and d-c lines are first in the world.

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The overall development of power construction is also reflected in the increase of per-capita consumption of electricity in the USSR. This increase is seen from the following figures: in 1913 the per-capita consumption was 14 kwhr/year; in 1928 it was 33 kwhr; in 1937 — 218 kwhr; in 1940 — 252 kwhr; in 1955 — 861 kwhr; and in 1958 — 1129 kwhr. By the end of the Seven-Year Plan period, the per-capita consumption should increase to 2200-2300 kwhr/year, exceeding present day per-capita consumption in Gt. Britain (2176), the West German Federal Republic (1860), and France (1393).

In 1929 electricity generation in the U.S.A. exceeded Soviet production by a factor of 19.4, and per-capita consumption in the U.S.A. was more than 25 times higher than in the USSR. By 1958 these figures will drop to 3.3 and 3.9, respectively. By 1965 per-capita consumption will approach that of the U.S.A.; the Soviet figure will be smaller by a factor of only 1.2-1.5. The present consumption in the U.S.A. is 4000 kwhr/year.

Technical advance has made possible an increase in the unit power of the plants. This has been accompanied by an increase in efficiency, and reduction in the investment cost per kilowatt for equipment and construction work.

Before the revolution there were only a few hydroelectric plants of low power in Russia: Alaverdinskaya (4800 kw) in Armenia; Murgab (1000 kw) in Turkmenia; and Turgusun (1000 kw) in the Altai Region. Starting with the GOELRO Plan, Soviet construction programs have brought about an increase in the average installed capacity of hydroelectric stations. This can be seen from Figure 74.

The increase in the unit power of installed equipment, which was particularly marked in the postwar period, has allowed Soviet hydropower engineering to catch up with the standard found in the western countries. The largest Soviet hydropower plants, Volga HEP im. Lenin (2300 Mw), Volga HEP im. XXII Congress of the CPSU (2530 Mw) and several plants now under construction, e.g., Bratsk HEP, Krasnoyarsk HEP, and Nurek HEP, are being equipped with large turbines of ratings up to 508 Mw.

Another important aspect of Soviet power construction is the steady introduction of automatic control. In 1945, about 0.25% of all hydropower was controlled automatically, while in 1949 the figure was 37%. Almost every regional power plant now has automatic control and remote control is used at about half of them. Much progress has been made in introducing automatic control of power systems. Today about 80% of the systems use remote-control facilities located at load-dispatch centers. These are sometimes located hundreds of kilometers from the controlled power stations.

In recent years, new techniques of automatic control have been adopted— automatic connection of power equipment, automatic frequency and load control, etc. This permits the gradual replacement of central dispatch centers by independent automatic control. In some power systems the new system has replaced the old by as much as 98.3% (in the district networks of Azerbaidzhan, Northern Osetia, and Stavropol).

Much attention is also devoted to increasing the efficiency of power construction (Table 35).

The prospects for Soviet hydropower construction are extremely bright. Waterpower resources constitute a third of the extremely large power potential of the USSR (conventional fuels and hydropower). These

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waterpower resources are estimated as being equivalent to 1590 billion tons of unit fuel. The share of hydropower in the total power supply can thus be increased to 35%.

TABLE 35

Efficiency of hydropower construction and utilization

	Period			
	1938-1941	1946-1951	1952-1958	1959-1965
Maximum station capacity Mw	330	600	2300	5000
Average station capacity, Mw	90	75	165	660
Mean daily production per station, million kwhr [sic]	200	300	800	3000
Annual hours of utilization	3100	4000	4800	4500
Construction work per thousand kwhr [sic]				
excavation	—	—	11.0	3.1
concrete placing	—	—	0.48	0.33
Investment per kw installed, rubles	3960	3400	3400	1600
Cost of electricity, kopecks [per kwhr]	3.8	2.4	1.7	0.85

This increase in hydraulic generation will be brought about by the harnessing of the great power potential of Siberia. This will be possible with reasonable levels of capital investment.

Soviet achievements in power construction are given prominence and recognition in foreign publications[4].

In 1959, a group of American senators visited the USSR and commented favorably on the progress of Soviet power construction[5].

In the article mentioned in note 5, it is brought out that Soviet industry makes its experience in hydropower construction available to foreign countries, and exports power equipment of up-to-date design.

The XXII Congress of the CPSU once again stressed the role of power construction as the basis for the future communist society.

Responding to the appeal of the Congress, Soviet engineers are exerting maximum effort to shorten construction times, to fulfill their assignments ahead of schedule, to increase labor productivity, and to keep down capital costs and operating charges. During the first half of the current Seven-Year Plan, Soviet constructors commissioned 22 million kw of new capacity. Many complex problems connected with the utilization of hydropower were solved. As an example, the construction of Dnieper HEP im. Lenin has made navigation possible over the whole length of the Dnieper. Many pumping stations and power plants were built on the White Sea-Baltic Sea Canal and the Volga-Don Canal, which link the Volga River and the Caspian, Baltic, and White seas with the Black Sea. Numerous very large storage reservoirs, called "artificial seas" have been created, the most important being the Moscow, Rybinsk, Kuibyshev, and Tsimlyanskii reservoirs. These developments radically changed the streamflow of the Volga, the Dnieper, and their tributaries, and made possible the solution of many land-reclamation problems in the arid areas of the Volga, and the southwest and south.

As Lenin has written, the Soviet people has all the prerequisites — natural wealth, a labor force, and (most important of all) the revolutionary zeal — to create a strong affluent state[6].

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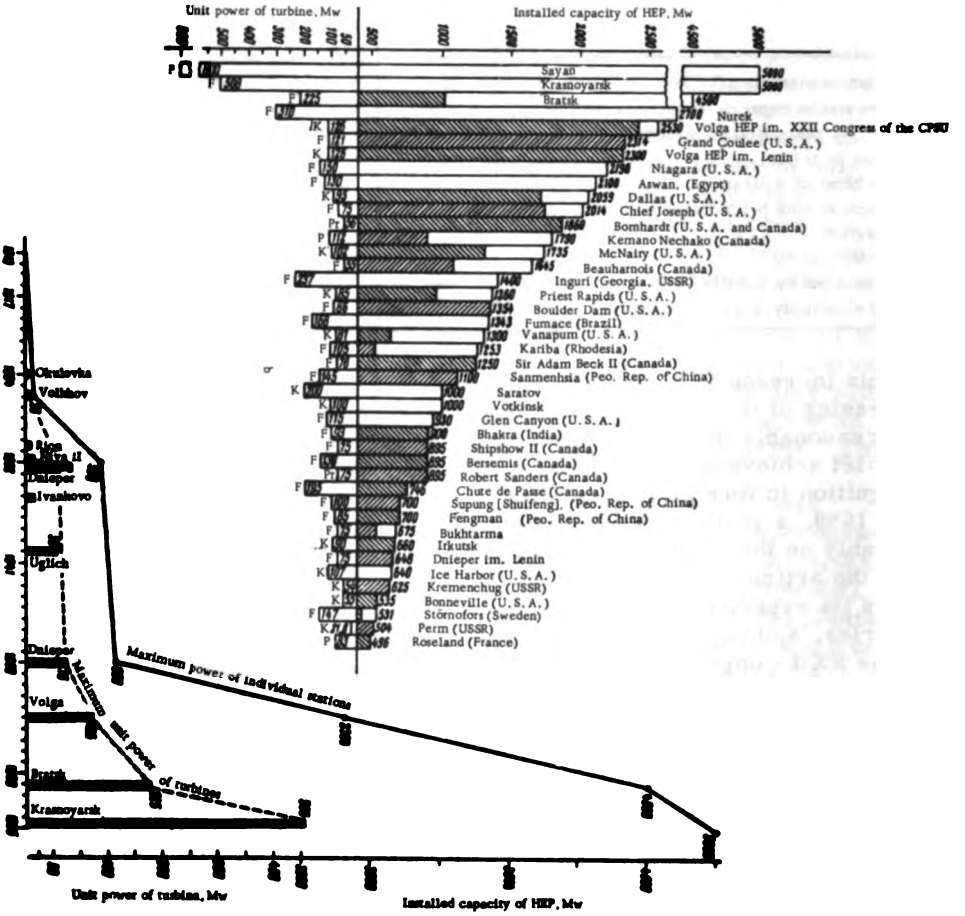

FIGURE 74. The development of hydroelectric power plants in the USSR and abroad

a — maximum capacity of hydropower stations and the unit power of plant in the USSR; b — large hydropower plants of the world — design capacity and installed capacity (cross-hatched area). Turbine types: F — Francis; K — Kaplan; Pr — propeler; P — Pelton.

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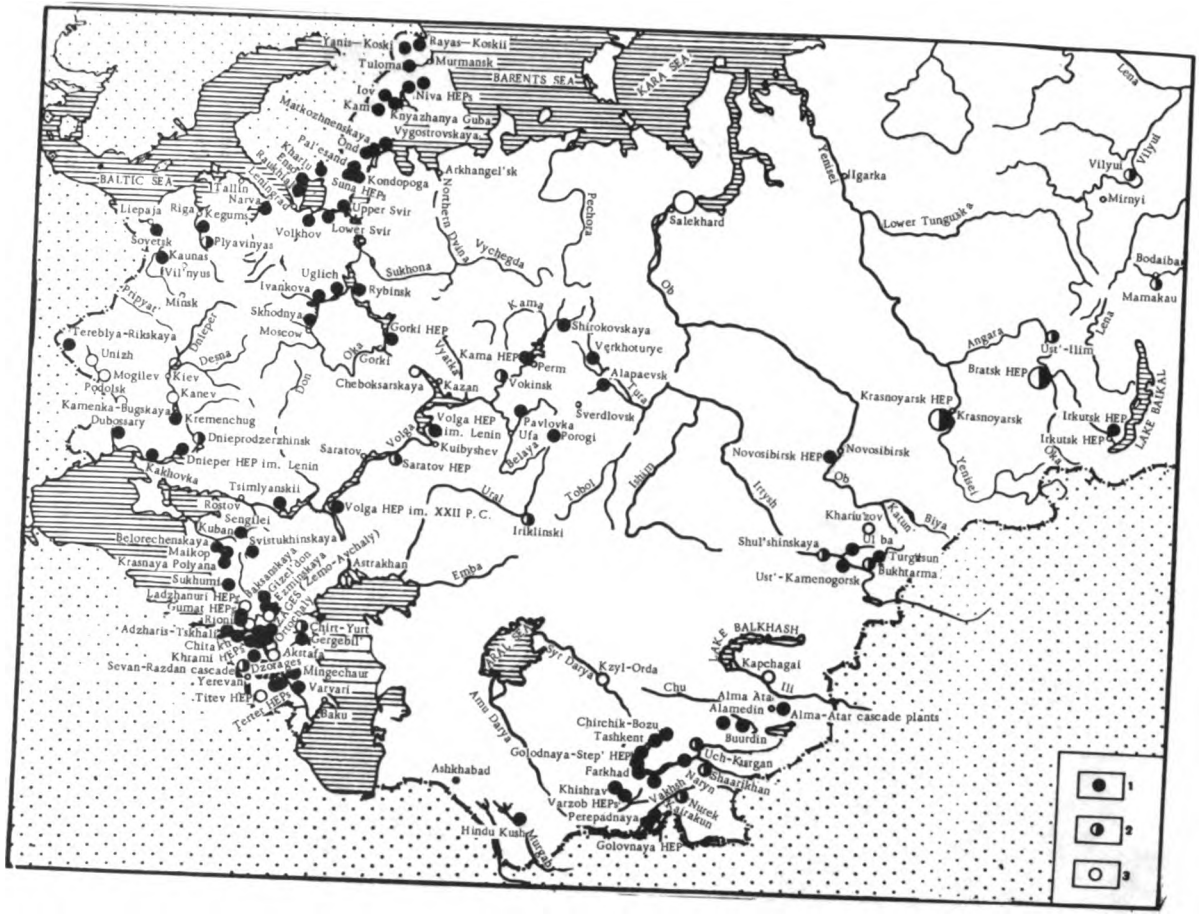

FIGURE 75. Location of Soviet hydropower plants

1 — operational; 2 — under construction; 3 — design stage

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The history of Soviet power construction as reflected in the series of medallions, "Landmarks in the Design and Construction of Hydroelectric Stations" (after N. A. Zimina)

1 — White Sea-Baltic Sea Canal; 2 — Volga-Moskva Canal; 3 — Khimki River-Landing Station; 4 — Volga-Don Canal im. Lenin; 5 — Volga HEP im. Lenin; 6 — Centenary of the Leningrad Metal Works; 7 — Third All-Union Hydrology Congress, Leningrad, 1957; 8 — 100 Years of River-Steamer Navigation; 9 — Volga HEP im. XXII Congress of the CPSU.

Working in many different environments from the Arctic to the "Burning South", the Soviet people is setting up large hydropower plants and extensive irrigation systems. In this way, the ideas of Lenin are being translated into fact. Entire rivers are being harnessed for power generation. During the fourth year of the Seven-Year Plan, the installed capacity of all Soviet power plants increased by 9 million kw (including 2.5 million kw hydropower).

An attempt has been made in this book to describe the great diversity and scale of Soviet power construction and to outline the trends of its future

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development. The successes obtained by the Soviet people in this field assist the advance of marxism-leninism in the construction of a new society. The achievements here described presage extraordinary growth in the national economy, a flourishing of science and culture, and the strengthening of man's power over nature.

NOTES

[1]Lenin, V.I. Sochineniya (Works), Vol.32, p.435.

[2]Economic Geography, No.2. 1951.

[3]Lenin, V.I. Sochineniya (Works), Vol.32, p.470.

[4]Report of General Ichner after his visit to the USSR, published in Engineering News Record, Vol.160, No.9, p.24. 1958. It should be noted that his report contains many inaccurate figures on Soviet power construction.

[5]An article by an American correspondent who accompanied an American delegation on its visit to the USSR was published under the title "American Senators Say USSR has Also Surpassed U.S.A. in Field of Hydroelectric Construction" appeared in Pravda on 2 December, 1959.

[6]Lenin, V.I. Sochineniya (Works), Vol.27, pp.134-135.

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EXPLANATORY LIST OF ABBREVIATED NAMES OF USSR INSTITUTIONS, JOURNALS, ETC. APPEARING IN THIS BOOK

Abbreviation	Full name (transliterated)	Translation
ASSR	Avtonomnaya Sovetskaya Sotsialisticheskaya Respublika	Autonomous Soviet Socialist Republic
Gidroproekt	Vsesoyuznyi Ordena Lenina Proektno-izyskatel'skii i Nauchno-issledovatel'skii Institut imeni S. Ya. Zhuka	All-Union Institute for the Design and Planning of Hydrotechnical Structures im. S. Y. Zhuk
GOELRO	Gosudarstvennaya Komissiya po Elektrifikatsii Rossii	State Commission for the Electrification of Russia
GRES	Gosudarstvennaya Raionnaya Elektricheskaya Stantsiya	State Regional Electric Power Plant
KhTGZ	Khar'kovskii Turbogeneratornyi Zavod imeni S. M. Kirova	The Khar'kov Turbogenerator Works im. S. M. Kirov
LMZ	Leningradskii Metalicheskii Zavod	Leningrad Metal Works
MISI	Moskovskii Inzhenerno-Stroitel'nyi Institut (imeni V. V. Kuibysheva)	Moscow Civil Engineering Institute (im. V. V. Kuibyshev)
MVTU	Moskovskoe Vyshee Tekhnicheskoe Uchilishche imeni N. E. Baumana	Moscow Technical College im. N. E. Bauman
Orgenergostroi	Byuro po Organizatsii Stroitel'stva Energeticheskikh Predpriyatii	Office for Organization of Construction of Power Establishments
TES	Teplo-elektrostantsiya	Thermal Power Plant
TsNIITMASh	Tsentral'nyi Nauchno-Issledovatel'skii Institut Tekhnologii i Mashinostroeniya	Central Scientific-Research Institute for Technology and Machine Building
VIGM	Vsesoyuznyi Nauchno-Issledovatel'skii Institut Gidromashinostroeniya	All-Union Scientific-Research Institute of Hydraulic Machinery Construction

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